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The Material of Interstellar Space*

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It is difficult to give an exact date to the beginnings of our present-day knowledge of interstellar material. If we consider the types of observation from which the existence and the nature of material in the spaces between the stars were eventually to be inferred it is necessary to go back to the observations by Herschel[1] of bright nebulae and dark regions in the sky in the latter part of the 18th century and to the observations by Huggins[2] and Secchi[3] of bright lines associated with particular gaseous atoms in the spectra of the diffuse nebulae in 1864 and 1865. It is indeed fitting in reviewing fifty years of progress in this fascinating branch of astrophysics to pay tribute to those pioneers whose early observations gave direction and inspiration to the work of later investigators.† Another man who should perhaps be honoured above all others is Barnard, whose work on the photography of the Milky Way was begun at the Lick Observatory in 1889 and culminated 30 years later in his magnificent "Atlas of the Milky Way"[4] from photographs made with the Bruce telescope of the Yerkes Observatory. This atlas not only contains some of the finest photographs ever made of the sky but the information which it contains as to the number and distribution of dark markings constitutes some of the most valuable evidence now available as to the existence of obscuring matter in interstellar space.

Early in the present century another type of observation of the greatest importance was initiated by Hartmann[5] who was the first to recognize the interstellar character of the lines H and K of calcium in the spectrum of δ Orionis. Lines of similar character had been previously seen by other observers, notably by Campbell and Wright in the spectrum of Nova Persei 1901[6] but Hartmann was the first to give them a definitive interpretation. He based his conclusion that they were due to absorption by gas of low density between the stars on the fact that they did not share either the orbital motion or the diffuse character of the other lines of δ Orionis which is a spectroscopic binary with a period of 5.73 days.

Another equally important clue to the nature of interstellar material was provided by Slipher[7] of the Lowell Observatory who found that

*The fourth paper in the series of Astronomical Summaries.

†Keeler, *Lick Pub.*, **3**, 165, 1894, gives an excellent account of his own and other early observations of the spectra of the nebulae by visual methods.

the spectra of certain of the diffuse nebulae did not consist of bright lines but were absorption line spectra similar to those of the stars in the immediate vicinity of the nebulae. From this he reached the conclusion, amply confirmed by later investigators, that the nebulae consisted in part of solid particles or dust which reflected the light of the stars without changing its character. This observation combined with those already mentioned made it clear that interstellar matter existed both in the form of gas and of finely divided solid particles. Since quite different observational methods are used in the study of the two types of interstellar matter it will be convenient to deal with them separately in the present discussion, beginning with the solid particles.

The Solid Particles

Apart from the spectra of reflection nebulae which have already been mentioned, the most convincing proof of the existence of solid particles in interstellar space is found in a comparison of the absorbing efficiency of finely divided solid material with that of gas. The work of Russell[8] and Trumpler[9] has shown that the density of gaseous material required to produce such general absorption as was noted by Barnard in his study of the Milky Way was hundreds of times greater than the best estimates of the density of the galaxy including both stars and interstellar material. On the other hand the absorbing power of solid particles of the order of size of the wave-length of light or even considerably larger is such as to produce the observed absorption without even approaching the limits of density set by the known dynamical properties of the galaxy. In the discussion which follows it will accordingly be assumed that any general obscuration observed in the galaxy or in connection with the spiral nebulae is due to finely divided solid particles. The matter of particle diameter will be discussed in more detail in a later paragraph.

Actual observed obscuration effects indicating the presence of absorbing matter in space may briefly be enumerated as follows:

(a) Numerous dark markings in the sky where the light of the stars appears to be dimmed or extinguished over considerable areas.

(b) Dark markings associated with the bright diffuse galactic nebulae in which not only stars but portions of the bright nebulae themselves appear to be obscured.

(c) The presence of a zone of avoidance in the galactic plane where no globular clusters or spiral nebulae are visible.

(d) The dark band usually associated with a spiral nebula when seen edge on.

(e) Departures from the inverse square law of brightness in the case of stars whose distances and intrinsic luminosities are known with reasonable certainty.

(f) The reddening with distance of certain stars of early type which are normally white or blue in colour.

The Coefficient of General Absorption. An early method of estimating the amount of general photographic absorption in the galaxy was that employed by Seares,[10] van de Kamp,[11] Shapley,[12] and Hubble[13] who studied the distribution of extra-galactic nebulae on photographs of the sky, on the assumption that the falling off of the numbers of such nebulae in low galactic latitudes was due to the effects of absorption by solid particles distributed within the galaxy. Counts of the nebulae were shown to vary with the latitude according to a cosecant law indicating the existence of a flattened slab of absorbing material in a plane coincident with that of the galaxy. The total absorption through the thickness of the slab at right angles to the galaxy (from pole to pole) was estimated to be from 0.5 to 0.8 stellar magnitude. A strict interpretation of the cosecant law would imply that the absorbing material was of uniform density but this result is a consequence of taking statistical averages and it is known (*e.g.*, from the presence of dark markings) that the actual distribution shows considerable irregularity.

More recent studies of the coefficient of general absorption are due to Trumpler,[14] Joy,[15] and Wilson.[16] Trumpler made use of the apparent diameters of open clusters to estimate their distances and employed slit spectra of individual stars to estimate their spectral types and absolute magnitudes. On the basis of the deviation of individual stars from the inverse square law of brightness he derived an average value of the general photographic absorption of 0.67 magnitude per kiloparsec. Joy's determination was based on a study of faint galactic Cepheids. He determined their distances from the galactic rotation effect in radial velocities and their absolute magnitudes from the well-known period-luminosity relation. His value of 0.85 magnitude per thousand parsecs is entitled to considerable weight because of the great average distance of the stars and the definiteness with which their absolute magnitudes could be fixed. Wilson's value of 0.65 per thousand parsecs for visual absorption (which would be approximately 0.77 per kiloparsec for photographic absorption) was based on data which included Joy's observations as well as practically all known stars which had been used for the determination of galactic rotation. In presenting his results Wilson stressed the evidence for irregularity of distribution of the absorbing material, and warned against conclusions based on the assumption that the coefficient is the same for all parts of the galaxy.

From the foregoing values of the general absorption coefficient it is possible to calculate the effective thickness of the absorbing stratum of solid particles from the amount of the total absorption due to van de Kamp and Hubble. They derived a value of the total absorption from pole to pole of the galaxy of from 0.5 to 0.8 stellar magnitude and, since the best value of the coefficient of general absorption is around 0.75 magnitude per kiloparsec, the effective thickness of the absorbing stratum comes out to be of the order of 1000 parsecs. It should, however,

be noted that an absorption coefficient obtained from objects close to the galactic plane may not be immediately applicable to optical paths which range from 10° to 90°. The extent of the absorbing stratum in the direction of the galactic plane cannot of course be unambiguously determined but it seems reasonable to suppose that it is co-extensive with the galaxy as a whole and that at great distances its optical thickness is great enough to produce the zone of avoidance in the galactic plane where no globular clusters or spiral nebulae are visible. It would further seem reasonable to attribute the dark band observed in photographs of spiral nebulae when seen edge-on to a similar stratum of absorbing material associated with these external galaxies. (See Plate IV.)

Selective Absorption. It is well known that many distant early type stars are yellowish whereas stars of the same spectral type when observed nearby are white or blue in colour. The effect is so marked in some instances that the distant objects of early B type normally of the order of 20,000° in temperature have colour temperatures which correspond to G type stars of 6,000°. It is not supposed that the distant early-type stars are actually so cool but rather that their true colours have been altered by the selective absorption of dust particles in interstellar space.

Measurements of colour index and spectrophotometric gradient both by photographic and photoelectric means have succeeded in establishing the existence of selective absorption beyond reasonable doubt. The precise relationship between absorption coefficient and wave-length is not, however, known with certainty, nor is it known whether a single law holds for all parts of the galaxy. In order to determine such a relationship it is necessary to start with the value of the coefficient of absorption referred to some mean wave-length, say λ 4250, corresponding to the photographic system of magnitudes, and then, with the aid of measures of colour excess or spectrophotometric gradient, compute the value which the coefficient would have for other wave-lengths. As stated above a good average value of the coefficient of general photographic absorption is 0.75 per kiloparsec. Numerous measures of colour index using photographic methods by Trumpler,[17] Seares,[18] Oort,[19] Schalen,[20] Zug,[21] and Smith,[22] as well as photoelectric observations by Elvey[23] and Hall,[24] and by Stebbins[25,26] and his associates, Huffer and Whitford, have indicated that the colour excess per thousand parsecs expressed on the international system is of the order of 0.12 magnitude. On this basis the coefficient of absorption for λ 5290, the mean wave-length corresponding to the visual system of magnitudes would be

$$A_v = 0.75 - 0.12 = 0.63.$$

The matter may be carried somewhat further by measures of spectrophotometric gradient and until recently measures of this sort made by Trumpler, Struve, Keenan, and Hynek,[27] Rudnik,[28] Greenstein,[29] and Hall have indicated that, to a first approximation, over the relatively

limited region of the spectrum ordinarily available to photographic methods, the absorption coefficient varies inversely as the wave-length (λ^{-1} law). On the basis of this law it is of course possible to make use of the observed spectrophotometric gradient for stars of known distance in conjunction with a well-determined value of the coefficient of absorption for a single wave-length to compute values for any other region of the spectrum. Actually this would be a questionable procedure since the λ^{-1} law is at best an approximation and recent photoelectric measurements by Stebbins and Whitford,[30] over a wave-length range of 7000 A (λ 3500 — λ 10,500), have indicated rather large deviations from it. Further progress in this interesting field requires the extension of the observations to longer and longer wave-lengths where the coefficient of absorption may be expected to drop to a small fraction of its value in the photographic region.

While this very brief discussion may not appear to do justice to the large amount of careful and laborious work which has been devoted to the study of selective absorption, the writer believes that the interests of this branch of science will be best served by stating that the law of selective absorption is as yet insufficiently known and may be a considerably more complex function of the wave-length than has hitherto been supposed.

Dimensions of the Particles. The dimensions and chemical composition of solid particles in interstellar space constitutes a fascinating field for speculation and study. The absorption phenomena mentioned in previous paragraphs call for particles of minute size but that does not exclude the possibility or rather the probability that larger particles are also present. The study by Watson[31] of hyperbolic meteors which are believed to come from outside of solar system suggests particles of the order of size of 0.5 cm to 5×10^{-2} cm diameter. No doubt still larger particles exist in limited numbers and it is possible that dark bodies of planetary or stellar size may be present as occasional wanderers in space.

Apart from the range represented by meteoric particles of 0.5 cm to 5×10^{-2} cm mentioned above, scientific investigation has been mainly concerned with particles of such sizes as are involved in the optical properties of reflection nebulae and the absorption of light in space. The following considerations, mainly due to Struve,[32] will give some idea of the limits within which such particle sizes may be found.

Studies of stellar motions by Oort[33] suggest an upper limit for the density of the galaxy of 0.09 solar mass per cubic parsec. In order to produce the observed values of absorption without approaching this limit the particle sizes must be smaller than 10^{-2} cm. Diameters between 10^{-2} and 10^{-3} cm are excluded by the absence of bright diffraction rings surrounding stars embedded in nebulosity so that the diameters of the most numerous particles must be smaller than 10^{-3} cm. On the other hand, particles smaller than 10^{-5} cm would result in the scattering

of blue light by reflection nebulae and this blue light would be expected to be strongly polarized. Since the colours of reflection nebulae are very little bluer than the stars which illuminate them and since they show little evidence of polarization it may be concluded that the average particle diameter is of the order of 10^{-5} cm or larger. Further, the application of Mie's[34] theory of the scattering of light by small particles to the λ^{-1} law of absorption which has been found to hold approximately for reddened B stars, results in an average size of the scattering particles of slightly greater than 10^{-5} cm. Actually, as has already been suggested, it is not to be expected that the particles will be of uniform diameter and the aim of present day studies of the matter is to deduce if possible the frequency distribution of particle diameters. Such a calculation has been made by Greenstein.[35] Basing his calculations on an extrapolation of the frequency distribution of hyperbolic meteors he has derived a relation in which the frequency of particle diameter is proportional to $a^{-2.8}$ where a is the diameter. Progress in this branch of the subject is mainly dependent on a more precise knowledge of the law of absorption. It is particularly important to extend the measures of absorption to longer wave-lengths since it is obvious that, if part of the absorption is non-selective, the coefficient of absorption will not show the expected approach to zero in this region. The question of the chemical nature of the absorbing particles is also of considerable importance in estimating their absorbing properties and the composition of meteorites suggests one approach to this problem. Any information as to the chemical nature which might be given by the appearance of lines or bands in the spectra of stars would also be extremely valuable. No such evidence is at present available but a number of unidentified interstellar bands or diffuse lines are known which might conceivably have such an origin.

Gases in Interstellar Space

The presence of gases in interstellar space is indicated by the following types of observation:

(a) The presence of atomic emission lines in the spectra of the diffuse nebulae as well as of other parts of the sky, where no easily visible nebulosity appears.

(b) The appearance in the spectra of stars of atomic absorption lines which cannot reasonably be attributed either to the atmospheres of the stars or the atmosphere of the earth.

(c) The appearance of certain molecular absorption lines in the spectra of stars which are similarly only explicable on the basis of interstellar absorption.

Atomic Emission Lines and the Diffuse Nebulae. The presence of gaseous material in certain diffuse nebulae has been known for many years by the atomic emission lines in their spectra. The Orion nebula

is the best example of this type, and its spectrum is characterized by lines due to H, He, O, and N in various stages of ionization. Dark nebulosity is also a feature of this nebula, and since a continuous spectrum accompanies the bright lines of this and a number of other diffuse nebulae[36] it is reasonably certain that there is some solid material in the form of fine particles mixed with the gases. The so-called "reflection nebulae," which exhibit absorption spectra similar to the stars in their immediate neighborhood, do not show emission lines, and the investigations of Hubble[37] have suggested the reason to be the absence of sufficiently early-type stars to excite an emission line spectrum. It thus seems a reasonable presumption that all diffuse nebulae consist of dust and gas, though the proportions of gaseous and solid material are not always the same.

One of the most interesting problems regarding diffuse nebulae is whether they are of purely local significance or whether they are condensations of a type of material which is generally distributed throughout interstellar space. Evidence pointing to a general distribution of solid particles throughout interstellar space has been given in the previous section. New evidence regarding the distribution of interstellar gases has been provided by the recent remarkable results obtained by Struve and Elvey[38] at the McDonald Observatory. Making use of a nebular spectrograph consisting of two prisms and a f 1 Schmidt camera in conjunction with a narrow plane mirror at an effective distance of 150 feet as a slit, they have discovered emission lines due to H, OII, NII, and OIII in many parts of the sky not hitherto associated with bright nebulosity. The location in the sky of the regions showing bright lines was such as to indicate that they were associated with groups of O-type stars. The distribution of emission within the regions suggested a stratification somewhat similar to that observed in the planetary nebulae. When OIII appears it is always near the centre of the emitting region, while H and OII and NII extend to greater distances and are sharply bounded on the outside. The lines due to oxygen and nitrogen are the well-known "nebular" type of resonance lines due to forbidden transitions between the two lowest levels of the atom. The average extent of the regions of nebulosity is of the order of several hundred parsecs. The limitation of the emission to a sharply bounded region surrounding a group of O-type stars is interpreted by Struve and Strömgren as a consequence of the absorption of short wave-length radiation in the process of ionization rather than to a limitation in the distribution of the gases responsible for emission.

These observations strongly suggest that material similar to that found in the diffuse nebulae is distributed throughout the extent of the galaxy and requires only an appropriate source of ultra-violet radiation to make it luminous. If this is the case, any information gained regarding the chemical composition of the diffuse nebulae is applicable to interstellar space as a whole, and it is reasonably certain that all atoms

known to be present in the diffuse nebulae are also constituents of interstellar space even though their lines may be too faint to be detected by the methods so far available.

Atomic Absorption Lines. The interstellar character of certain atomic absorption lines was originally discovered as a result of their so-called "stationary" character. When such lines were observed in the spectra of binary stars they did not share the oscillatory displacements shown by the stellar lines but remained fixed in position throughout the period of the binary. Similarly in the case of stars with large constant velocities, the smaller velocities shown by the interstellar lines frequently made it clear that they did not arise in the stellar atmosphere. In the spectra of novae also the interstellar lines have been observed to remain fixed both in intensity and position while the emission and absorption lines of the star exhibited the astonishing sequence of variations commonly associated with these objects. The narrow-line character associated with absorption by interstellar gas also makes it possible in many instances to distinguish them from stellar lines. The stellar lines of many early type stars are broad and diffuse, many times wider than the atomic interstellar lines and there is usually little difficulty in distinguishing between them.

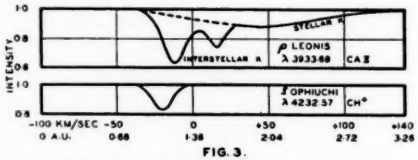

FIG. 3.

NARROW ATOMIC AND MOLECULAR LINES DUE TO INTERSTELLAR GAS.

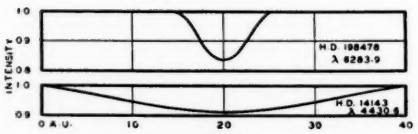

FIG. 4.

BROAD INTERSTELLAR LINES OF UNKNOWN ORIGIN

Profiles by C. S. Beals, Dominion Astrophysical Observatory. Spectra of ζ Ophiuchi taken by A. McKellar. The interstellar K line of ρ Leonis is double. (Note that horizontal scale of Figure 3 is 12.3 times that of Figure 4.)

For many years the H and K lines of calcium discovered by Hartmann,[39] and the two sodium doublets at λ 5893 and λ 3302 discovered by Miss Heger[40] were the only lines appearing in interstellar spectra which were known to be due to interstellar matter. Recently discoveries

by Dunham and Adams[41] and Dunham[42] have added lines due to TiII, CaI, and KI, while in a paper which has just appeared Dunham and Adams[43] have reported the definite identification of lines due to FeI. Table I contains a list of the atomic lines so far identified. All the interstellar absorption lines which have been identified correspond to transitions from the lowest atomic energy level of the atom, and in the case of TiII, where the lowest term (^{4}F) consists of four sublevels, only lines arising from the lowest sublevel have been observed. This leads to the conclusion that under the conditions of interstellar space, sublevels above the normal state are depopulated by forbidden transitions.[44] A similar situation exists in connection with certain molecular lines to be discussed in the next paragraph.

TABLE I

INTERSTELLAR LINES OF ATOMIC ORIGIN

Absorption Lines			Emission Lines		
Atom	λ	Multiplet	Atom	λ	Multiplet
NaI	3302.38	$3^2S - 4^2P^o$	H	4340.48	$2^2P^o - 5^2D$
NaI	3302.98	$3^2S - 4^2P^o$	H	4861.34	$2^2P^o - 4^2D$
NaI	5889.98	$3^2S - 3^2P^o$	H	6562.81	$2^2P^o - 3^2D$
NaI	5895.94	$3^2S - 3^2P^o$	OII	3726.12	$a^4S^o - a^2D^o$
KI	7664.88	$4^2S - 4^2P^o$	OII	3728.91	$a^4S^o - a^2D^o$
KI	7698.98	$4^2S - 4^2P^o$	OIII	4958.91	$2p^3P - 2p^1D$
CaI	4226.74	$4^1S - 4^1P^o$	OIII	5006.84	$2p^3P - 2p^1D$
CaII	3933.68	$4^2S - 4^2P^o$	NII	6548.1	$2p^3P - 2p^1D$
CaII	3968.49	$4^2S - 4^2P^o$	NII	6583.6	$2p^3P - 2p^1D$
TiII	3072.97	$a^4F - z^4D^o$			
TiII	3229.18	$a^4F - z^4F^o$			
TiII	3241.97	$a^4F - z^4F^o$			
TiII	3383.78	$a^4F - z^4G^o$			
FeI	3719.95	$a^5D - z^5F^o$			
FeI	3859.92	$a^5D - z^5D^o$			

Absorption Lines Due to Molecules. The fact that all interstellar atomic absorption lines arise from the lowest level of the atom and that even the sublevels of extremely low excitation potential are not populated, suggested that any absorption by molecules in interstellar space would involve transitions from only a few of the lowest rotational levels of the normal state of the molecule (for lines so far observed only the two lowest rotational states are involved). On this basis each "band" as observed in laboratory or stellar spectra would consist of one or more isolated narrow lines which could only be distinguished from atomic absorption by measurements of wave-length and, in some cases, of relative intensity.

McKellar[45] has determined from laboratory data the wave-lengths to be expected from a number of such common molecules as would likely be present in interstellar space, and with the aid of observations by Adams[46] four lines due to CH, one of which was previously noted by Swings and Rosenfeld,[47] and three due to CN have been definitely identified. More recently, three additional lines observed by Adams and Dunham have been shown to be due to CH^+ by Douglas and Herz-

berg.[48] The wave-lengths and indentifications of these lines are given in Table II. All molecular lines so far indentified exhibit the narrow line character shown by the atomic lines. The molecular lines so far observed are very faint and it seems probable that greater telescopic power combined with higher spectrographic resolution would result in many more discoveries.

TABLE II

INTERSTELLAR ABSORPTION LINES OF MOLECULAR ORIGIN

Molecule	Line	Interstellar λ	Lab. λ
CH	R(1)	4300.34	4300.31
CH	$P_{Q_{12}}(1)$	3890.25	3890.23
CH	$Q(1) + Q_{R_{12}}(1)$	3886.44	3886.39
CH	$R_2(1)$	3878.81	3878.77
CN	P(1)	3875.77	3875.77
CN	R(0)	3874.62	3874.61
CN	R(1)	3874.02	3874.00
CH+	R(0)	4232.58	4232.57
CH+	R(0)	3957.72	3957.71
CH+	R(0)	3745.33	3745.30

Unidentified Interstellar Absorption Lines. Interstellar lines as yet unidentified fall into two classes: (1) Narrow lines which are similar in character to those already identified and which are presumably of similar origin. A list of such lines is given in the second column of Table III and it seems reasonably certain that these lines are due to absorption by gases in the form of atoms or molecules. (2) Lines of a definitely diffuse character which differentiates them sharply from the interstellar lines referred to above. All lines of this character which are at present known were discovered by Merrill[49] and his collaborators in the course of investigation of atomic interstellar lines. Most of them are moderately diffuse, from 4 to 10 A in width, and could easily be mistaken for stellar lines were it not for their stationary character and the correlation of their intensities with those of the sodium D lines, which

TABLE III

UNIDENTIFIED INTERSTELLAR LINES

Diffuse Lines		Sharp Lines	
λ	Int.	λ	Int.
4430.6*	10	3579.04‡	0
4760†		3934.3§	0
5780.55	3		
5797.13	1		
6202.99	1		
6269.99	1		
6283.91	6		
6613.9	2		

*This indication of intensity reflects the equivalent width of this line. The actual existence of the line is frequently difficult to detect because of its great width and small central depth.

†A broad feature tentatively identified by Merrill as an interstellar line. (Private communication.)

‡May be due to 3.0 band of CH+ system.

§May be due to NaH (*Ap. J.*, **93**, 11, 1941.)

has been definitely established by Merrill and Wilson. One line (λ 4430) has a width of 40A and cannot ordinarily be detected by an eyepiece inspection of a spectrum but shows up clearly on microphotometer tracings. Merrill and Humason[50] have conclusively demonstrated its stationary character by measurements made on the spectrum of the star H.D. 163181 which is a single-lined binary with an extreme range of over 700 km/sec. Beals and Blanchet[51] and Miss Sherman[52] have shown that its intensity is correlated with distance in the same manner as the intensity of the K line of calcium and there seems no reasonable doubt of its interstellar origin.

Present knowledge of the physical condition of interstellar space makes it difficult to account for these lines by molecules of gas, although Swings in a paper kindly communicated in advance of publication has suggested that homonuclear molecules such as C_2 and O_2 may be so distributed among rotational states as to give rise to unresolved features of considerable width. An attractive alternative suggestion is that the diffuse lines are due to absorption by solid particles in interstellar space. Such an hypothesis is given credence by a fair correlation of the intensities of the diffuse lines with space reddening found by Merrill and Wilson. There is as yet no confirmatory evidence from laboratory spectra to support such an hypothesis but the absorption spectra of common gases in the solid form are very little known and until more data of this sort are available the matter must remain in a state of uncertainty.

Motions of Interstellar Gases. Present knowledge of the motions of interstellar gases depends largely on radial velocity measures of lines due to Ca^+ and Na. Individual velocities are due to many sources, since the interstellar velocity is a by-product of most velocity measures of early-type stars. The largest single body of data is due to Plaskett and Pearce[53] although notable contributions have since been made by the Mount Wilson observers,[54] who included both calcium and sodium lines in their measurements. Analyses of these velocities carried out by Plaskett and Pearce[55] and by Merrill and Sanford[56] have led to the following conclusions: (1) The velocities of calcium and sodium lines are closely similar, and cases where discrepancies occur can usually be traced to blends with stellar calcium lines. (2) The residual radial velocities after the solar component has been removed are largely influenced by galactic rotation, and show the familiar double-wave relation

$$v = \mathbf{r}\, A \sin 2(l - l_0) \cos^2 b.$$

Plaskett and Pearce's solutions led to the interesting result that the mean distances for the interstellar lines came out almost exactly one-half those for the corresponding stars. A strict interpretation of this result leads to the conclusion that the absorbing material is uniformly distributed between the star and the observer. There is every reason

to believe that this conclusion is statistically accurate although there is almost certainly considerable local irregularity of distribution. (3) A study of the residuals in solutions for galactic rotation indicates the presence of peculiar motions in the interstellar medium having maximum values of the order of 20 km/sec. These observations suggest some irregularity of motion and distribution which may be referred to as turbulence. Further evidence confirming the presence of turbulent motions in the interstellar cloud was provided through the discovery by Beals[57] that the atomic interstellar lines due to calcium and sodium in a few bright stars were complex in character. These observations were confirmed by the Mount Wilson observers[58] and recently Adams[59] has published the results of high dispersion studies of fifty early-type stars which indicate that complex structure is the rule rather than the exception for the lines of interstellar calcium and probably for other atoms as well. In one case as many as five components have been detected with a velocity range of over 60 km/sec. The only reasonable explanation of these observations is to be found in the random motions of individual clouds within the general stratum of absorbing material in the galaxy. Additional evidence pointing in the same direction is found in the older observations by Buisson, Fabry, and Perot[60] and by Campbell and Moore,[61] of irregular motions of as much as 13 km/sec between different parts of the Orion nebula.

Spitzer[62] in recent discussions of the dynamics of the interstellar medium has pointed out that the viscosity as well as the effects of diffusion will be small in the dust gas mixture and that there will accordingly be nothing to prevent the existence of coherent clouds over considerable periods of time. He further draws attention to the effect of radiation pressure on the material of the clouds. According to his calculation this effect is greater for the solid particles than for the gas but the net effect on the gases is appreciable and it would appear reasonable to suppose that the radiation pressure from suitably located groups of stars may account for some of the observed cloud motions.

Relation between Interstellar Line Intensity and Distance. Investigations by Struve[63] and by Plaskett and Pearce[64] on the basis of eye estimates of line intensity first indicated the existence of a relationship between the distance of a star and the intensity of interstellar lines appearing in its spectrum. Later, spectrophotometric measures on interstellar line intensity became available as a result of the work of Beals,[65] Williams,[66] and Merrill, Sanford, Wilson, and Burwell.[67] For the purpose of correlating these line intensities with distance there are available a few trigonometrical parallaxes of nearby stars, some proper motion data, the distances of a few clusters derived by Trumpler's method, and the powerful method of deriving the distances of groups of stars provided by the theory of galactic rotation. Curves relating intensity and distance have been published by Williams,[68] Beals,[69] Wilson and Mer-

rill,[70] and by Sanford.[71] Agreement between different curves is reasonably good although there is evidence of systematic differences between the Victoria and Mount Wilson measures. The recent compilation of Evans[72] constitutes an excellent review of the present situation, and he gives the following straight-line relation between intensity and distance:

$$r \text{ (kiloparsecs)} = 2.38\ D$$
$$r \text{ (kiloparsecs)} = 3.00\ K.$$

Here r is the distance, D is the mean equivalent width in angstroms of the two sodium D lines, while K is the corresponding equivalent width for CaII K. While the errors are estimated to be of the order of 20 per cent, the use of such a relation probably provides the most accurate method now available for estimating the distance of an individual early-type star.

Ionization in Interstellar Space. The first calculation of the ionization of interstellar space was made by Eddington.[73] He pointed out that, although the total energy density of radiation in interstellar space corresponds to a temperature of 3.2° K, a body which absorbs selectively in the short wave-length region may attain a very much higher temperature owing to the richness of starlight in radiation of high frequencies. Assuming the mechanism of selective absorption to be the photoelectric ionization of atoms with ionization potentials in the range 5 — 10 volts, he derived a temperature of 10,000° K* for atoms capable of absorbing in this range. Making use of this value of the temperature in connection with the appropriate dilution factor he calculated the ionization of sodium and calcium atoms from the equation

$$(1 - x)/x = N_e\,(h^3/2\pi mRT)^{2/3}\,e^{h\nu/RT} \qquad (1)$$

where x is the proportion of ionized atoms, N_e is the number of free electrons per cc, T is the temperature and the other constants of the equation have their usual significance. Results indicated the following relationships between the numbers of atoms in neutral and ionized states, triple ionizations of Ca and double ionizations of Na being negligible:

CaI/CaII = 1/300,000 CaII/CaIII = 1/400 NaI/NaII = 1/1,000,000.

A later investigation by Gerasimovič and Struve[75] led to an essentially similar result for the state of ionization of sodium and calcium atoms. It had been known for many years that the intensities of interstellar NaI and CaII lines were of the same order of magnitude, and in 1933 Beals[76] carried out spectrophotometric measures of lines in the spectra of ξ Persei and 9 Camelopardalis which showed that the equivalent widths in km/sec of the sodium lines were somewhat greater than the

*Swings (*M. N.*, **97**, 212, 1937) has since pointed out that the corresponding temperature for selective absorption in the region beyond 10,000 A (involved in transitions between the lowest rotational states of molecules) is of the order of 5° K.

corresponding lines of CaII. These results, interpreted in terms of the above figures for ionization, would require a 300-fold greater abundance of sodium than calcium, a result difficult to accept in view of the known fact that, terrestrially, sodium is only four times as abundant as calcium.

Eddington[77] later suggested that the approximate equality of the intensities of sodium and calcium lines was a consequence of saturation in a rectangular profile due to the Doppler broadening produced by galactic rotation. Such a mechanism would result in a definite relation between intensity and velocity which was shown by Beals,[78] and later by Sanford,[79] and by Wilson and Merrill,[80] to be non-existent except for the most distant stars. Their observations suggested rather that the width of the interstellar lines was largely due to turbulent motions in the absorbing medium. While this conclusion would not of itself entirely rule out the argument based on saturation, the observation by Beals[81] that the intensities of sodium lines in certain nearby stars were of the order of twice those of calcium could not be accounted for on this basis.

Barring an excessive abundance of sodium in interstellar space it thus appeared that some important factor had been left out of the calculations and that the actual state of ionization of sodium and calcium in interstellar space was much lower than had previously been supposed. Such a conclusion received strong support from the discovery by Dunham[82] of an interstellar line at λ 4226 due to CaI in the spectrum of χ Orionis. On the basis of measured intensities of lines due to CaI and CaII in χ Orionis in connection with known values of the atomic constants, Dunham[83] derived the following result for the relative numbers of atoms in the neutral and singly ionized states:

$$\mathrm{CaI}/\mathrm{CaII} = 1/3{,}500.$$

Making use of this ratio in an equation of the same general form as equation (1), and using values of the density and quality of interstellar radiation which were similar to those adopted by Eddington except that he made a correction for the value of selective absorption by solid particles, Dunham found for the density of free electrons in interstellar space a value of the order of 10 per c.c. This high value of N_e was difficult to explain if the ionization of sodium and calcium (or indeed of other common atoms in terrestrial relative abundance) were the source of the free electrons, and this gave rise to another theoretical difficulty to add to those already encountered.

What may prove to be a solution of the difficulty is found in the previously mentioned discovery by Struve and his collaborators[84] of hydrogen emission lines in extensive areas of the sky not associated with visible nebulosity. Struve[85] and Strömgren[86] have discussed the observations from a theoretical point of view, and conclude that most of the hydrogen in the emission regions must be ionized. If we apply to interstellar space modern ideas concerning the abundance of hydro-

gen in the stars, then a great majority of the interstellar atoms will be hydrogen, and if most of these atoms are ionized they will provide a source of free electrons not contemplated in the earlier calculations.

Making use of values of N_e which range from 1 to 10 per c.c. and which correspond to the order of density derived by Strömgren for interstellar hydrogen, Struve and Dunham have derived values of the abundance of sodium relative to calcium which range from 17 to 7, and Struve expresses the opinion that the discrepancy between theory and observation represented by the relative intensities of NaI and CaII lines has now been largely removed. Without dissenting from an opinion which is supported by the best recent observations we may point out that there remain a few difficulties which may delay a final decision on this point. These include: (1) The restriction of hydrogen emission to relatively limited regions, suggesting that a large proportion of interstellar hydrogen remains unionized; (2) the rather large density of interstellar space required by the values of N_e given above; and (3) lack of complete knowledge concerning the absorbing qualities of the interstellar medium due to solid particles, atoms, and molecules in the critical short wave-length regions involved in the ionization of calcium and sodium.

Density of Interstellar Matter. Estimates of the density of interstellar matter are necessarily subject to great uncertainty. Dynamical considerations give an upper limit of 6×10^{-24} gm per c.c. for the galaxy as a whole, but Oort's recent discussion indicates that the partition of mass between visible stars and invisible interstellar matter cannot be estimated with any degree of accuracy. He does suggest, however, that interstellar matter is probably a small fraction of the whole, and this implies a value of the order of 10^{-24} gm per c.c. for the interstellar material in agreement with an estimate made by Eddington nearly twenty years ago.

TABLE IV

DENSITY OF GASES IN INTERSTELLAR SPACE

Atom	Density (Dunham)	Density (Struve)
Hydrogen	1.7×10^{-23}	2.7×10^{-24}
Oxygen	...	2.3×10^{-26}
Sodium	4×10^{-27}	4×10^{-29}
Potassium	7×10^{-28}	...
Calcium	7×10^{-28}	7×10^{-30}
Titanium	8×10^{-30}	...
CH	2×10^{-29}	...
CN	1.5×10^{-29}	...

Dunham has given 5×10^{-25} gm per c.c. as the mean space density of meteors on the basis of the number entering the earth's atmosphere per second, but this density may be a characteristic of the solar system. Dunham estimates the density of solid material repsonsible for absorption as 10^{-26} gm per c.c. Greenstein's estimate of the space density of solid particles based on an extrapolation of the observed frequencies

of hyperbolic meteors (meteors from outside the solar system) is 2×10^{-25} gm per c.c. These estimates are probably the best available at the present time, but they can hardly be regarded as definite enough to form the basis of a judgment of the distribution of interstellar mass as between solid particles and gases.

Recent estimates of the density of interstellar gases made by Dunham[87] and Struve[88] on the basis of absorption and emission-line intensities are given in Table IV. This table suggests that the interstellar gas consists mainly of hydrogen and that its estimated density approaches or exceeds Oort's limit for the density of the galaxy as a whole. Most astrophysicists would be reluctant to accept the idea that the mass of the galaxy is mainly in the form of interstellar gas, but if we are to place any faith in these estimates such a possibility cannot be entirely excluded. The figures for the density of hydrogen depend on the values of N_e given in a preceding paragraph, and any change in present ideas regarding ionization would have an effect on the results.

General Discussion. Present-day literature relating to interstellar matter reveals highly satisfactory progress in almost every part of the field and it appears unlikely that the foundations of the subject as they exist at present will be drastically altered by subsequent investigation. That is not to say that the subject is approaching a stage where further work would be unprofitable. On the contrary, it is likely to remain for many years one of the most fruitful fields of astrophysical investigation. As in numerous other branches of astronomical science many of the investigations conducted to date are of the character of general surveys. They have well served their purpose of revealing the general physical nature and distribution of interstellar matter but many details remain to be filled in and the amount of observational work required to produce finally satisfactory values for the absorbing properties of matter in different parts of the galaxy is still very great. There also remain a few outstanding puzzles to be solved and no doubt others will arise as the development of the subject proceeds. Several aspects of the general problem have particularly impressed themselves on the writer during the preparation of this review and will briefly be discussed in the following concluding paragraphs.

1. A recurrent theme in nearly all studies of interstellar absorption is the irregularity of distribution of interstellar matter throughout the galaxy. Both photographs of the sky showing dark markings and photoelectric and spectrophotometric studies of stars in localized regions demonstrate the irregular distribution of solid particles, while the recent magnificent Coudé spectrograms by Adams of interstellar lines make it clear that there may be as many as five separate clouds of interstellar gas, with velocities in the line of sight ranging from —4 to +60 km/sec between the star and the observer. This lack of homogeneity interferes with many generalizations and suggests that much of the future

work in interstellar matter may be concerned with detailed and intensive studies of individual clouds bringing to bear for the purpose every observational method available to modern astrophysics. While such a tendency toward concentration on localized aspects of a problem is a normal development in any branch of science after the general outlines have taken form, it is particularly applicable to the study of interstellar matter now that observations of unquestioned accuracy have shown that irregularity of distribution is the rule rather than the exception. An obvious first step is the study of the immediate vicinity of the sun for which stars of many spectral types are available. For the investigation of more distant clouds main reliance has heretofore been placed in early type stars but eventually it will no doubt be necessary to use the more numerous stars of later spectral types, pushing the observations to as faint magnitude as can be observed with the most powerful of modern equipment.

2. One of the significant problems in the field of interstellar matter has to do with the relationship between wave-length and the coefficient of absorption by solid particles. Preliminary investigations have indicated that the coefficient of absorption expressed in stellar magnitudes per unit distance varies approximately as λ^{-1}. There is, however, no *a priori* reason to expect that the λ^{-1} law should hold precisely and the most recent (and probably the most accurate) observations available by Stebbins and Whitford have indicated that there are large deviations from it. It is also by no means certain that the law is the same for all parts of the galaxy. It has been made abundantly clear that further progress is dependent on an extension of the observations to a greater range of wave-length. Such an extension has already been undertaken by Stebbins and Whitford who have secured observations covering the range λ 3500 to λ 10,500 and who hope shortly to be able to cover a greater range from λ 3300 to λ 12,500. It would be highly desirable to cover the same range of spectrum by photographic spectrophotometry, since this method is capable of such great accuracy in fixing the wave-length of the region studied. The types of photographic plates now on the market are such as to make observations of this kind entirely feasible even though it might be necessary to utilize more than one type of plate to cover the entire range. The photographic and photoelectric observations should provide the mutual confirmation so highly necessary when precise values of a somewhat elusive quantity are desired. The investigation of still longer wave-lengths is dependent upon other types of receivers and there is some question as to whether methods at present available would suffice for the distant and relatively faint stars involved in heavy absorption. With increased telescopic power it may eventually be possible to make use of the thermocouple or bolometer to investigate objects like the red giants at wave-lengths of 20,000 or 30,000 A. Such observations should lead to a much more definite idea of the true form of the absorption curve and should definitely settle the question as to

whether there is an appreciable amount of straight obscuration as compared with selective absorption.

3. Perhaps the outstanding unsolved problem in the study of matter in the spaces between the stars is represented by the diffuse interstellar lines discovered by Merrill, none of which has been identified with any known terrestrial substance. While these lines were discovered as a by-product of an investigation of atomic interstellar lines they may eventually prove to be of major importance in determining the nature of material in interstellar space. Reasons have already been given for believing that they are probably not due to material in gaseous form. If this conclusion is correct then the diffuse lines must have their origin in absorption by solid material presumably in a finely divided state. No coincidences have been found with known absorption bands of solid substances and it would appear that further exploration of this possibility would require a laboratory investigation involving extensive resources of equipment and personnel. Not only common solids such as metals, rocks, meteorites, etc., would require to be studied but also common gases, the absorption spectra of which in the solid form are very little known. Such a laboratory investigation, if sufficiently comprehensive, might also shed light on the difficult question of particle diameters and the absorbing qualities of mixtures of particles which so far have been studied mainly by purely theoretical methods.

4. The density of interstellar material is closely bound up with the question of ionization and the values of atomic constants. As such constants are refined and as additional atoms and molecules are identified the present discordances between estimates of the density of interstellar gas by different investigators should tend to disappear. Present values derived from hydrogen appear rather high and may well have to be revised unless new arguments based on the dynamics of the galaxy can be adduced to support them. The relative number of sodium and calcium atoms as indicated by the intensities of interstellar lines no longer appears to raise any insuperable difficulties and with the solution of this problem one of the major paradoxes, which has enlivened discussion of interstellar matter for many years, becomes a thing of the past.

A major problem of galactic structure is the distribution of mass as between the various types of bodies found in the galaxy. It has usually been assumed in the past that the lucid stars supplied the larger part of the mass but recent estimates of the density of hydrogen gas indicate values which may equal or exceed Oort's limit for the density of the galaxy as a whole. A relatively low density of 10^{-25} gm per c.c. has been estimated for the solid particles mainly responsible for absorption but it is possible that larger amounts of mass are associated with larger bodies. The question as to the existence of significant quantities of mass in the form of gross rocks or dark bodies of planetary or stellar

mass is necessarily of the greatest interest to astrophysicists even though at present the subject remains in the realm of pure speculation. It is possible that advances in knowledge of stellar evolution, more refined values for the density and dynamics of the galaxy, and perhaps types of observation not hitherto contemplated may eventually serve to illuminate even this very obscure branch of astrophysical knowledge.

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DOMINION ASTROPHYSICAL OBSERVATORY, MARCH 13, 1944.

Sunspots and the Weather

By WALTER G. BOWERMAN

(Continued from page 169)

In presenting some notes on the development of our information regarding sunspots, it is of interest to observe how recent is this knowledge. Galileo first discovered the existence of sunspots in 1609, shortly after he invented the telescope. The monthly sunspot numbers of Wolfer begin with January, 1749, although the data for years prior to 1833 are not the result of systematic observations. In 1801 Sir William Herschel made some valuable suggestions as to a possible influence of sunspots on terrestrial affairs. In 1847 Heinrich Schwabe discovered that sunspots move in cycles. In 1878 W. S. Jevons suggested that the periodicity of commercial crises might be related to the sunspot cycles. Although in many particulars he was on the wrong track, the paper was

a remarkable pioneer achievement. In 1903 Langley's calculations suggested that what has been regarded as a solar "constant" was in reality a variable. In 1908 Hale discovered by use of the spectroscope that sunspots form magnetic fields. In 1911 Ellsworth Huntington found three Sequoia trees over 3,000 years old and plotted the history shown by their rings as evidence bearing upon the influence of sunspot cycles. In 1919 the Smithsonian Institution began to keep daily records of the amount of solar energy that reaches the earth, at stations established throughout the world. Since 1924 the Mount Wilson Observatory has for some years kept records of the variations of the ultraviolet light received from the sun. In 1928 the International Astronomical Union began to publish *daily* data of the sunspots in the central zone of the sun. This has been recently discontinued. This should prove of distinct value in certain researches, because spots in the lower latitudes of the sun ought to affect the earth more strongly than the other spots.

During recent years a close relationship has been found between the solar cycle and various terrestrial phenomena. The best established association is that of the sunspots and the magnetic changes going on in the earth. During the last 100 years there has been a remarkable correspondence between these two phenomena. There is a continual ebb and flow of electric currents for 100 to 300 miles above the earth, and sunspots make violent disturbances in these giant atmospheric currents. It has been estimated that the greatest disturbance in the earth's magnetism occurs from one to four days after a spot has passed its central position on the sun. The widespread use of radio sets has brought home to the public the occasional very disturbing effect of sunspots on radio reception. Sometimes all radio communications have been wiped out momentarily, except those which are transmitted at very low frequencies. Variations in solar radiation, particularly in the ultraviolet, have been suspected to be capable of producing profound biological and physiological changes. The thickness of the skin of fur-bearing animals and the thickness of tree-rings have also been related to the sunspot cycles.

In 1934 Mata and Shaffner showed a rather close relationship between sunspots and industrial activity. For the period 1876 to 1930 the curve of the index of industrial production was in fairly close fit with the differences of the sunspot areas from year to year, smoothed by a four-year moving average. The curve of solar radiation coincided with all the major depressions, but there were two short business panics, 1903-1904 and 1913-1914, which followed respectively the volcanic eruptions of Mt. Pelée in the West Indies and Mt. Katmai in Alaska. Several cubic miles of volcanic dust are thrown to such great altitudes by these explosions that the finer portions are nearly two years in reaching the lower level of the region of equal temperatures. Much of this dust, as it reaches the more humid portions of the atmosphere, may gather sufficient moisture to reflect and thus seriously interfere with the sun's

radiation upon the earth. Thus there is often a time-lag of 1½ or 2 years between the explosion and a cold spell at some distant area.

As a result of their extended researches Mata and Shaffner made some distinctions which should be useful to other investigators. "In temperature fluctuations for the whole world, the volcanic dust factor is the most important one. The small deviations above normal seem to be related to sunspot minima, but all the sharp drops in temperature are clearly related to volcanic eruptions. On the contrary, in the business curve the solar factor is the main one and the volcanic dust disturbance is secondary. The solar factor in the world temperature curve is the curve of the total amount of sunspots, while in the business curve it is the increase or decrease of sunspots." Their conclusion regarding temperature and the influence of active volcanoes accords with that of Humphreys. In the 1940 edition of his book, "Physics of the Air," there is a chart in which a pyrheliometric* curve is added to that of the sunspots, the total being in remarkable agreement with the curve of world temperatures. Although the pyrheliometric curve covers only a few decades, the tabulation of sunspots and temperatures extends back to 1749. A separate table shows the volcanic eruptions which have affected world-temperatures. The worst of these during the last two centuries was Asama, Japan, which burst forth in August, 1783, preceded in June by a volcano in Iceland and followed in 1785 by Vesuvius, Italy. The world temperatures in 1784-1786 were the lowest on record. In April, 1815, Tomboro, Sumbawa, Malay Archipelago, erupted in great volume and had a distinct influence in producing "the year without a summer" (1816). The material brought into the upper air by this explosion has been estimated at 36 cubic miles. The greatest explosion since 1783 was Krakatoa, Malay Archipelago, which blew off its upper half in August, 1883, just a century later. Unusual cold was experienced in 1884-1886 but the influence near Philadelphia, Pa., was not great, although February and March, 1885, were among the coldest on record.

In passing, it may be noted that for magnitude and frequency of explosions Vesuvius seems to have held its own with other volcanoes during historic times. In August, 79 A.D., it destroyed the city of Pompeii, and the preservative effect of the lava was such that centuries later archeologists obtained data of great value from the ruins, by which much of the mode of life of people in the first century of the Christian era was reconstructed. In December, 1761, Vesuvius caused the worst eruption recorded anywhere since the year 79; the ash cloud was said to be 30 miles high. Its neighbor Aetna seems to have been rather harmless by comparison, although in November, 1928, its destroyed the town of Mascati and much of the village of Nunziata.

In April, 1932, there was a great volcanic eruption in the Andes

*Measuring solar radiation by its thermal effects.

between Argentina and Chile, and it may be more than a coincidence that February, 1934, was the coldest February on record in Philadelphia, Pa., and New York City. It also included the coldest day of all record.

In Table J a tabulation was given of the 17 years during the period 1749-1939 in which the average number of sunspots exceeded 100 a day. This dealt with the maxima, and while these are more spectacular, it is the minima that come with more regular intervals, so that a double cycle between minima differs little from 22½ years. A similar tabulation of minima should be of interest. Accordingly Table M shows the 33 years in which the monthly average number of sunspots was less than ten.

TABLE M

YEARS WITH YEARLY AVERAGE LESS THAN 10 SUNSPOTS DAILY

Year	Daily Average	Rank	Duration From Prior Date (Yrs.)		Year	Daily Average	Rank	Duration From Prior Date (Yrs.)	
1755	9.6				1855	6.7			
					1856	4.3		23	
1775	7.0		20						
					1867	7.3		11	22
1797	6.4								
1798	4.1	10	23		*1878*	3.4	7	11	
1799	6.8				1879	6.0			
1808	8.1				1888	6.8			
1809	2.5	5			*1889*	6.3		11	
1810	0.0	1	12		1890	7.1			23
1811	1.4	2							
1812	5.0				1900	9.5			
					1901	2.7	6	12	
1821	6.6				1902	5.0			
1822	4.0	9							
1823	1.8	4	13		1911	5.7			
1824	8.5				1912	3.6	8		
				23	*1913*	1.4	3	12	
1833	8.5		10		1914	9.6			22
					1923	5.8		10	
					1933	5.6		10	
					1934	8.7			

It will be observed that the year 1810 was a complete blank as to sunspots. It was the center of a five-year period of lows and the adjacent year 1811 was next lowest in the entire 191 years, 1749-1939, ranking equally, in fact, with 1913. Several writers have contended that there is a 100 year periodicity underlying the briefer cycles of sunspots, but such theories must remain speculative in view of the short period during which sunspots have been observed and counted. The next such minimum in sequence would be at about the year 2010.

There is, however, some advantage in building up a hypothesis as to the longer cycles of sunspots. One purpose is to understand better the rise and fall of civilizations of the past as weather and climate

changed, and another is to have some picture, however vague, of the most probable "shape of things to come." The most appealing work of this kind has been done by Ellsworth Huntington. In "Civilization and Climate" he said "Fairly recent studies of glaciation show there have been pulsations over the centuries. At some ancient times a vast mantle of ice spread to within 30° of the equator, while at others almost tropical conditions prevailed as far north as Greenland. The idea of climatic instability is now so well grounded that most geologists have rejected the nebular hypothesis. During historical times there have been changes in climate, but less violent and marked than in earlier ages. The tree-rings in California (sequoias) show the distinct changes in moisture which are confirmed from data in western Asia such as the rise and fall of lakes and the Caspian Sea. When the Mayas flourished in Yucatan and Guatemala and great civilizations existed also in Egypt, Greece, Mesopotamia, and Nineveh, the climatic zone of fertility and cyclonic storms (changes) was farther south than at present. It then had much the relationship to the present that we find now when sunspots are active. We may infer then that the solar radiation was the chief cause of the changes in climate and the downfall of ancient civilizations."

In "Medical Climatology," Dr. C. A. Mills wrote in similar vein. "The Grecian and early Roman crest in human affairs came in the relatively cold centuries from 500 B.C. to 200 A.D. With the warmth and northward shift of the storm belt from 200 to 1000 A.D., the European balance of power shifted well northward to the Teutonic and Scandinavian peoples. This warm period seems to have passed its peak around 850 A.D. The centuries from 1000 to 1900 A.D. were colder and stormier than during the Dark Ages. At about 1850 A.D. another cycle was finished, and we are now almost a century along into a succeeding long upthrust of temperatures. The one millenium of world warmth that has fallen within historical times coincided with man's marked decline during the centuries of the Dark Ages. Apparently we are now entering another recurring millenium of world warmth. There has been a spreading northward of tropical diseases in the very unusual warmth since 1929. It may be that leprosy, yellow fever, and plague will again seriously menace people of temperate regions, as sleeping sickness, dysentery, and malaria have already been doing in recent years. The growth of air commerce may foster the spread of tropical disorders; it also intensifies the need for more knowledge of the weather. Solar radiation as influenced by the sunspots seems one of the major forces regulating our weather and climate. The sunspots are probably controlled by planetary influences upon the sun's mass. Perhaps we shall some day find a scientific basis for ancient beliefs in the potency of heavenly forces."

On this latter point of planetary influences the following explanation has been given by Dr. Stetson. "The nearest planets to the sun are Mercury, Venus, the Earth, and Jupiter. The usual assumption is that

the attraction of the planet for the sun causes tides in the solar atmosphere as the moon causes tides in the oceans of the earth. Professor E. W. Brown of Yale showed in 1900 that every 9.93 years Saturn is in line with Jupiter and the sun, so that the tide-raising force of Saturn, which is about one-third that of Jupiter, is added to Jupiter's effect. By combining this 9.93-year interval with the period of Jupiter's revolution about the sun, 11.86 years, he could reproduce most of the times of the occurrences of sunspot maxima. But in some years there were quite distinct deviations. Now Mercury and Venus come together on the same side of the sun once every fifteen months, and a marked interval of fifteen months has been noted between secondary maxima in the sunspot cycle. A number of reasons can be given as to why the force of Jupiter and its period of revolution should be predominant and accord so nearly with the sunspot period. Incidentally the zone for maximum tidal stress on the sun occurs near 45° latitude, not far from the zone where the first sunspots start at the beginning of a cycle."

Probably the most ambitious attempt to estimate the specific sunspot cycles of the past from varied data is that of H. W. Clough. He amassed a vast collection of records of rainfall, severe winters, the stages of the Nile, growth of sequoia trees, earthquakes, the aurora borealis (northern lights), and wheat prices in England. Drawing curves from these and smoothing them, he reconstructed what seemed to be the most probable cycle of sunspots extending as far back as 300 A.D. Covering a period of 1,632 years, he found 148 maxima of which only 17 occurred during the years 1749 and later (for which Wolfer's tables show monthly numbers). Incidentally 17 of his maxima were frankly interpolated, presumably for lack of concrete evidence. In Table N are shown the number of maxima arranged in each case by the number of years since the last prior maximum; thus the total number is 147, as the first one in the series does not appear.

TABLE N

NUMBER OF MAXIMA IN H. W. CLOUGH'S TABULATION

Years Since Last Prior Maximum	Years 300-975	Years 975-1930	Total
7	1	2	3
8	5	11	16
9	10	8	18
10	9	14	23
11	14	14	28
12	7	13	20
13	9	12	21
14	3	7	10
15	2	2	4
16	1	2	3
17	0	1	1
Total	61	86	147

The one cycle of 17 years occurred at the beginning of the 19th century and one of the three cycles of 7 years took place a generation later. In

fact the extremes were relatively more numerous during the later period than during the Dark Ages. In general, however, the prevailing opinion among experts is that the turbulence and violence of solar upheavals are less today than in earlier centuries. H. W. Clough believed that he could find recurrent periods of 37 years, 83 years, 300 years, and 1,400 years in various terrestrial phenomena.

More than three centuries earlier Francis Bacon described in his essay "Vicissitudes of Things" a 35-year cycle of weather. The idea came to him from the Netherlands and he found confirmation in British records. This same cycle has been found by later observers and is called the Brückner cycle; it is really made up of two periods, 35 and 50 years. Dr. Richard Gregory, a distinguished meteorologist of Great Britain, has vouched for the following two statements. (1) If the period since the middle of the year 1204 is divided into intervals of 44½ years, the first half of each such interval has always been colder than the second half. (2) If the period since the middle of the year 1115 is divided into intervals of 89 years, there has been only one exception to the rule that the first half of each such interval is always colder than the second half. It may be observed that in a period of steadily rising temperatures both of these statements are necessarily true, as, for example, during the period since 1870. That they have also held during nearly all of the previous six or seven centuries is noteworthy. The period of 44½ years is very close to twice a double sunspot cycle. Measuring from minimum to minimum the latter has been very nearly constant and Dr. C. G. Abbot found 22.6 years as the normal period. The dry warm half of a Brückner cycle yields on the whole better crops than the cool wet half. At the end of the warm half of the cycle the farmers tend to be rich and at the other end poor. Hence migrations may be expected to be related to this cycle.

The period from 1917 to 1938 was upon the whole warmer than any equal period during the last 150 years. According to the theory, which has had such a long series of confirmations, the weather from 1939 to 1961 is to be warmer than this. The farmers may be expected to be successful and prosperous, but many of the concomitants of unusual warmth may be anticipated. Thus termites would make fresh inroads upon wooden structures in the northern states, as they have already been doing since 1929. Then, as Dr. Mills has pointed out, tropical diseases, such as malaria, dysentery, and sleeping sickness, may be looked for farther north than heretofore. The tendency will be for the climate of Canada to become more inviting and the latitudes of greatest energy and achievement to be farther north even into Canada.

According to E. N. Munns,* records of fire in America, based on examinations of many trees, indicate a close correlation between fire and sunspot cycles. This would suggest that in certain years a larger num-

*Conference on Cycles, p. 73.

ber of fire-wardens and foresters should be used than at other periods. The year 1946* is to be a time of sunspot minimum and warmth and 1951* a year of maximum and relative coolness.

W. J. Humphreys has indicated some of the practical results to agriculture which are made available by the knowledge of sunspot cycles. The temperature range from sunspot maximum to minimum varies roughly from 1° to 2° F., while that of volcanic dust is about the same, and occasionally greater. In the summer a change of 1° F., produces a latitude shift of equal temperatures (isotherms) by 90 miles. Thus at minima (as in 1946) cereals may be grown 50 to 200 miles farther north than at maxima (as in 1951). This alone is of great practical import to people living near the thermal limits of crop production. A decrease of 1⅓° F. in average yearly temperature may hold over by a year the maturing of a crop of sugar cane; this would occur, for example, in 1951 at a maximum in the sunspot cycle.

In dealing with a relatively new subject such as sunspots and the weather, one is naturally inclined to view with scepticism every presumed fact which the pioneer investigators set forth. However, in considering the matter as related to medicine, mortality, and morbidity, it seems desirable to mention briefly some of the indications which have been brought forward. These may lead to further studies of the facts in confirmation or refutation. The two chief investigators in this field, whose work has come to my attention are C. A. Mills and W. F. Petersen.

Dr. Mills regards the increased blood pressure of Orientals who migrate to the northern United States as due to the climatic drive and as unrelated to food supply. He found marked decreases in blood pressure during the prolonged heat-wave of July-August, 1934, and states that his own fell from 135/90 to 90/60. The life insurance companies might well test the blood pressures of applicants during prolonged hot spells. If Mills is correct, substandard lives may erroneously have been recorded as standard during such periods.

Leprosy is most rampant in areas of tropical heat and climatic stagnation such as the lowlands of India, the Philippines and the East Indies. With their low energy level the people give little concern to hygiene or control of even the most deadly infections. At altitudes above a mile leprosy is rare, even at the equator. Leprosy patients should be moved to high altitudes or to a climate like North Dakota's,

*When prophesying the doctors differ: While Messrs. Clayton and Abbot have indicated 1946 as a probable minimum year, Drs. Stetson and Stewart have been more inclined to expect it in 1944. If one had in mind the combined numbers, which include both the outgoing cycle and the incoming cycle, and the other were referring to the first appearance of the new cycle, then both could be right. For there is usually a lag of a year or two between the first appearance of the new cycle of spots and the low point in the combined data, of which the official Zurich numbers are composed. As a matter of fact, some of the new spots were observed in a high latitude of the sun as early as June, 1943.

rather than kept in Louisiana, as they now are. I have brought this suggestion to the attention of Surgeon General Parran.

Diabetes deaths are most prevalent in lands with the highest sugar consumption, which are usually also those regions with the most stimulating climate. Patients with diabetes or toxic goitre would be well advised to migrate to regions of lower climatic energy, where the stress of life is less severe.

People with chronic respiratory infections—pneumonia, colds, sinusitis, tuberculosis—would do best in the southwestern states, where major storm changes are infrequent.

Acute appendicitis deaths have been found relatively most numerous in the path of the polar storms down the western plains. They are not only more frequent in the hot summer months, but also more often fatal. Air-conditioning is now making it possible for hospitals to provide appendicitis patients with protection against the deleterious effects of heat, during and after the operation.

The higher homicide rates in the southern states, among Negroes as well as whites, probably represent the lower level of social inhibition that is universal in the warmer regions of the earth. The highest rates, at Kansas City and Memphis, are where the northern cyclonic storms and the southern heat meet.

People who have suffered heat shock would do much better if they would migrate to such a climate as is found in Oregon and Washington in the Pacific Northwest. This is the one most ideal place to avoid the extremes of heat and cold climate. The stimulating effect of the climate is great, but the temperature is always moderate.

Rheumatic infections are ten to twenty times as frequent in the worst areas of storm zones as in the calm warmth of the tropics. Rheumatic heart disease is especially frequent in the cooler, more stormy parts of the temperate zones. Such patients should be moved to near the Mexican border at moderately elevated sites. This would give a stimulating day-to-night temperature change, without the harmful atmospheric turbulence of northern storms.

Excessive climatic drive in our northern states is the reason for our restlessness and inability to relax; it entails a more irritable nervous system with less complacency, contentment, calm, and freedom from care. People with mental instability would do better in the non-stormy Southwest.

Dr. Petersen finds that gastric and duodenal ulcers have a consistently high prevalence in northern latitudes and practically disappear in southern latitudes and the tropics. Furthermore they appear chiefly in the thin-bodied, nervous individuals and only rarely in those of the roly-poly type. He considers the abdominal disorders are primarily due to vasomotor and neuromuscular dysfunction rather than to bacterial infection. The infrequency of gall-bladder troubles in Java is asso-

ciated with the absence of fats and oils from the diet of those tropical people.

Dr. Petersen made a graph of tuberculosis death rates in Chicago plotted with sunspot activity from 1855 to 1935 and found that when a sunspot cycle began there was a definite trend upward in the tubercular mortality. Deaths from toxic goitre have their peak several years after the peak of sunspots in each cycle. The great surgical clinics might make commercial use of knowledge of the peak load in these diseases. They have developed logically enough in the path of the prevailing cyclonic storms, of which Mayo's is the center. Hippocrates was right when he said 2,400 years ago that all disease is fundamentally due to interference with the supply of air to the tissues and that this is related to vascular spasm.

Dr. Abbot has reported that, although the total energy of the sun's radiation varies by only about 5%, the variation in the ultraviolet rays is at times as much as 100%. "Ultraviolet rays produce certain changes of chemical structure in fats and oils which are the source of those traces of hormones so extraordinarily important, all out of proportion to their infinitesimal occurrence in the growth and health of animals." The number of sunspots controls the amount of ultraviolet rays that reach us. As the electrical particles coming from the sunspots strike oxygen atoms in the higher zones of our atmosphere, they form ozone, and this forms the Heaviside-Kennelly layer which absorbs the ultraviolet rays of less than about 290 millimicrons of wave-length. Dr. Abbot has stated that if ultraviolet rays of less than 290 millimicrons were to reach us, they would destroy human sight and tissues, while if the screening effect extended to the rays of 320 millimicrons, all human and animal young would suffer rickets. Under such a sword of Damocles do life and health exist on the earth.

A survey of some practical advantages of studying fundamental causes of the weather would be inadequate without some reference to the work of Dr. Irving P. Krick of California. He uses the air-mass-analysis technique which originated at the Geophysical Institute at Bergen, Norway. In 1939 he began to publish weather predictions for one month in advance, with excellent results. The principle which he follows is that the weather in temperate zones is caused by clashes between cold masses of air from the polar regions and warm masses from the tropics. From these are derived "cold fronts" and "warm fronts," which as a rule remain relatively of fixed position. Most of the major motion-picture studios are connected by teletype wire with the Krick laboratories, and they have found his prophecies to be better than 90% correct. Sporting events are arranged in accordance with his predictions as to weather. Fuel-oil companies with a national market arrange deliveries according to the Krick forecasts of frigid weather. Fruit growers in California are using his services, especially after the very severe

cold in January, 1937, which he had prophesied several months in advance. Selected forecasters from the United States Weather Bureau are sent to California Institute of Technology to study under Dr. Krick; and investigate his methods. He recognizes that long-range weather forecasting is not yet an exact science, but he is still trying to make it become so.

Dr. Krick says, "Think of the times that lack of exact knowledge as to future weather conditions has changed the history of the world. Napoleon lost his army in Russia because of early and unusually heavy snows. Poland in 1939 might have withstood the German invasion until Allied help came, if the usual September rains had not failed. The Germans may, in fact, have had advance notice of this from Bauer of Frankfort. English bombers will always have advantage over German, because of prevailing storm winds blow from west to east in Europe. If Holland floods her canals, a heavy freeze may again turn the water to solid ice, over which tanks and motorized fighting units could pass."

Dr. Krick explains that "the pattern of movement of the great masses of polar and tropical airs across the Northern Hemisphere which controls the long-term weather trends tends to follow for six months at a time a general configuration discernible after March 21 and September 23, the spring and fall equinoxes."

Although in the preceding pages I have kept the discussion fairly well within the subject—Sunspots and the Weather—it is evident that many important elements have been omitted. Indeed even a 400 page book would seem fragmentary in dealing with such a massive subject. No mention has been made of earthquakes or of hurricanes, tornadoes, and giant cyclones. Most experts agree that temperature and precipitation are the two most important factors in the weather, and these are the two which I have dealt with particularly. Most people have noticed that the effect of temperature is dependent on humidity. Thus a temperature of 89° F. in New York City may be much more uncomfortable than 102° F. in West Virginia or Iowa, due to the humidity on the North Atlantic coast. In fact the relationship became so evident a few years ago that the suggestion was made that comparisons be made by a composite figure which might be called "humiture." From the observation of joint readings on about 80 occasions, I have observed a general relationship somewhat as follows:

TABLE O

TYPICAL SUMMER READINGS AT NEW YORK CITY

Temperature	Humidity
100°F.	40%
90	57
80	74
70	91

What we have in Table O is a simple straight-line relationship, such

that for 10° F. drop in temperature there is a 17% increase in humidity. It is because of this marked inverse relationship that we have mixed feelings amid changes of temperature which are often thirty or more degrees in a single day. Having been long accustomed to the apparent harmlessness of such material variations, it may be surprising to read the following from Ellsworth Huntington. "The best students of glaciation agree that during the glacial period the mean temperature of the earth as a whole was probably not more than 10° or 15° F. cooler than now." In his "Principles of Human Geography" he wrote, "At New Haven, Connecticut, the years 1920-1939 averaged 2°.7 F. warmer than the coldest twenty-year period. This is equivalent to moving New Haven 130 miles south, as to Atlantic City." The explanation is of course that an *average* (mean) temperature variation is far more significant than an equal fluctuation in a single day. Furthermore an average variation covering "the earth as a whole" might be distinctly smaller than the corresponding average for any single place, since deviations of opposite sign would tend to cancel each other. Nevertheless the above quotations are particularly informative because I think the popular impression of the glacial period (Ice Age) is of an earth where everything everywhere is covered with ice, and all temperatures are markedly below freezing.

In preparing the latter portion of the above paper, in which the literature is reviewed, I have relied heavily upon the writings of the experts, whose chief publications are listed in the appended bibliography. The interested reader will naturally wish to consult these more extended publications.

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11. "Weather for Sale" by Helen N. Satterlee in Satevepost, Feb. 10, 1940.

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The Planets in June, 1944

NOTE: Greenwich Civil Time is used unless otherwise stated. To obtain Eastern War Time, subtract 4 hours; Central War Time, 5 hours, etc. The information is taken from the *American Ephemeris and Nautical Almanac.*

Sun. During this period the sun will move from $4^h\,35^m$, $+22°\,0'$ to $6^h\,35^m$, $+23°\,12'$. It will be at its greatest declination north on June 22, the time of the summer solstice. By the end of the month it will have moved south only about a quarter of a degree, a distance approximately equal to the radius, from its farthest point north. Its course begins in Taurus and ends in Gemini, which will render these familiar winter constellations invisible.

Moon. The phases of the moon will occur as follows:

	d	h
Full Moon	June 6	19
Last Quarter	13	14
New Moon	20	17
First Quarter	28	18

It will be nearest the earth (at perigee) on June 12, and farthest from the earth (at apogee) on June 27.

Mercury. For the first few days of the month, Mercury will be barely visible on the eastern horizon just before sunrise, a short distance south of the sunrise point. It will, however, move eastward more rapidly than the sun and very nearly overtake it in right ascension by the end of the month.

Venus. Venus will spend this entire period in the glare of the sun's rays. Its motion eastward will be at very nearly the same rate as that of the sun. The paths of these objects will not be quite parallel. The moon will move from a position a little south of the sun to a position a little north of it. On June 27, the date of superior conjunction, the distance between the centers of the discs will be less than half a degree. Venus will, therefore, be very near the sun's limb at that time, a phenomenon which, unfortunately, cannot be observed without some means of reducing the intense sunlight.

Mars. Mars will continue to move eastward more slowly than the sun. The sun will move two hours during the month while Mars will move one hour and nine minutes. Mars will be a few degrees south of the sun and at the end of the month will set in the twilight.

Jupiter. Jupiter will be a brilliant object in the evening sky during the month. It and the bright star Regulus will form a conspicuous pair of objects. The changing aspect of its brighter satellites will be, as always, a source of interest for the user of a small telescope.

Saturn. Saturn will be in conjunction with the sun on June 21, the sun passing less than a degree north of the planet on this date. This planet, therefore, like Venus, will be unobservable during this period.

Uranus. Uranus, having been passed by the sun on May 30, will rise before the sun. It will, however, be deep in the twilight until just before the end of the month.

Neptune. Neptune will continue to be favorably situated for observation as soon as it becomes dark during this period. Its position on June 15 will be $12^h\,8^m$, $+0°\,43'$.

Occultation Predictions for June, 1944

(Taken from the *American Ephemeris*)

Date 1944	Star	Mag.	IMMERSION Greenwich C.T.	IMMERSION *a*	IMMERSION *b*	IMMERSION Angle E from N	EMERSION Greenwich C.T.	EMERSION *a*	EMERSION *b*	EMERSION Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
June 9	50 Sgtr	5.6	3 39.8	−1.7	+2.7	41	4 24.4	−0.7	−0.5	324
30	80 Virg	5.8	2 11.6	..	..	180	2 47.7	..	..	236
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′										
June 11	γ Capr	3.8	11 13.5	−0.7	+1.8	19	12 5.1	−2.5	−1.8	296
11	δ Capr	3.0	14 47.4	−0.3	−0.3	59	.. ..	..	..	..
17	B.D.+10°401	6.2	8 45.5	+0.1	+0.7	114	9 22.5	+0.3	+2.3	203
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′										
June 5	γ Libr	4.0	2 16.7	−1.2	+2.4	68	3 1.4	0.0	−1.6	342
5	η Libr	5.6	8 17.5	..	..	32	8 37.6	..	..	6
11	δ Capr	3.0	14 29.3	−0.7	+1.2	29	15 27.1	−1.7	−1.6	282
Occultations Visible in Longitude +98° 0′, Latitude +30° 0′*										
June 5	γ Libr	4.0	2 50.8	−6.5	+8.7	40	3 8.4	+3.5	−9.0	15
5	η Libr	5.6	8 52.0	−1.1	+0.6	51	9 36.8	−1.3	−3.3	335
9	50 Sgtr	5.6	3 2.8	+0.1	+0.4	109	4 0.2	−0.7	+1.2	262
11	γ Capr	3.8	10 47.5	−1.7	+1.8	36	12 0.7	−2.5	−0.7	277

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

*Computation by Tecla Combariati and J. Lynn Smith, communicated by Captain J. F. Hellweg, Superintendent U.S. Naval Observatory.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

The annual report for 1943 shows only too vividly the effect of war upon the activities of our members and those who have assisted them. Only one observer has been able to make a large contribution to our total, namely Professor Mohd A. D. Khan of India, who for many years has been endeavoring to advance meteoric astronomy in his great country. Despite the obstacles which the numerous duties of a professional life entail, since 1933 he has made notable personal contributions, only part of which have been worked up for radiants as yet.

The table that follows is much abridged, as it seemed wholly useless to repeat all the tabular matter that appeared in the December, 1943, "Notes" and which covered the work of the Society from July 9 to August 25, so far as had then been reported. The total given there was 4,298 meteors. The poor showing for most of us for the rest of the year was not due wholly to indifference or laziness. On many nights when showers were expected certain members were ready to observe but clouds prevented work or cut down to a minimum the meteors actually seen. The lack of gasoline also prevented parties from going to places in the country, on special nights. And finally extra duties kept many from having any free time that they could devote to meteors. As for fireballs, the *Hydrographic Bulletin*, U.S.N., printed only one report in 1943 instead of the usual hundred or so, as their space was needed for other things. This cut down largely the number of fireballs reported. Incidentally, once the war is over, the writer hopes to have the chance to search out and copy the reports in the Hydrographic office that are on file and not published. Also it is known that observations have been made by men in service who have not been able to send them in. We hope these will eventually reach our files.

The height and other data on a good many fireballs were derived and published in "Meteor Notes" during 1943. A reprint, consisting of the December "Notes," was prepared separately and has been mailed to all non-members in appreciation for their help. All members will receive the usual Flower Observatory Reprint containing all the "Notes" for 1943, in the near future, its publication being unavoidably delayed. A list of new members for 1943 was published in the March, 1944, "Notes." Members who have not sent in their $1.00 dues for 1944 are asked to do so without further delay. A cordial invitation is extended to all persons, men and women, who are interested in meteoric astronomy to write us with a view to joining the American Meteor Society. We need more members in every state, but some states do not have a single active observer.

A.M.S. Report for 1943

Observer and Station	Nights	Meteors	C or P
A.A.F.I., Philadelphia, Pa.			
Felice, Joseph, North Hills, Pa.	1	4	P
Gorson, Robert, North Hills, Pa.	1	3	P
Klein, Emil, North Hills, Pa.	1	5	P
McKannan, David, North Hills, Pa.	1	2	P
Pflaum, Charles, North Hills, Pa.	1	3	P
Reilly, Miss Edith, North Hills, Pa.	1	6	P
Shaffer, Francis, North Hills, Pa.	1	6	P
Smith, Miss Lois, North Hills, Pa.	1	1	P
Shutts, Roland, North Hills, Pa.	2	18	P
Anderson, Paul, Beechwood, Mich.	6	111	P
Dole, R. M., Cape Elizabeth, Me.	7	37	P, C
Green, Gordon, Lancaster, Pa.	1	11	P
Hart, A. E., Chattanooga, Tenn.	1	28	C
Jewett, Miss Mary L., Grandview, Tenn.	3	17	C
Kessler, Edwin III, Corpus Christi, Texas	5	10	P
Kessler, Edwin III, Camp Wigwam, Harrison, Me.	1	9	P
Khan, Mohd A. R., Begumpet, Deccan, India	81	1044	P
Khan, Mohd A. R., Begumpet, Deccan, India (April to December, 1942)	69	476	P
Liller, Bill, Atlanta, Ga.	2	21	P
Leerman, Joseph, Baltimore, Md.	2	11	C
McClelland, Robert { 77° 43′ 20″ / 39 59 45	6	83	P
New Haven Group, New Haven, Conn.			

Observer and Station	Nights	Meteors	C or P
Corbett, Milton T., Yale Observatory, New Haven	1	4	P
LeRoy, Olive G., Yale Observatory, New Haven	1	15	P
Neale, J. J., Yale Observatory, New Haven	1	13	P
Rademacher, Mrs. E. S., Yale Observatory, New Haven	1	11	P
Warren, Miss Mary K., Yale Observatory, New Haven	1	11	P
Roques, Paul E., Los Angeles, Calif.	2	6	P
Ross, Frank, Omaha, Neb.	2	22	P
Woodburn, Joseph J., Jr., Philadelphia, Pa.	13	112	C
Total		2100	
Telescopic Meteors:			
Fernald, Cyrus F., Wilton, Me.		58	
Flower Observatory, Upper Darby, Pa.		3	
Fireballs		132	
Photographs by R. M. Dole		3	
From July 9 to August 25		4298	
Grand total for 1943		6594	

NOTE: In the last column, P denotes that the meteors observed were plotted, C that they were counted.

Flower Observatory, Upper Darby, Pennsylvania, 1944 April 24.

Contributions of the Society for Research on Meteorites

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles 24

Further References on the Early History of the Tucson, Arizona, Meteorites

P. J. McGOUGH
Flagstaff, Arizona

ABSTRACT AND INTRODUCTION

The following four additional references on the history of the Tucson, Arizona, meteorites, the so-called "Irwin-Ainsa" and "Carleton" irons, have all been taken from an old Tucson newspaper, the *Arizona Citizen*, of dates January 15, April 1, and April 8, 1876. These references, which supplement those contained in the article that appeared in *C.S.R.M.*, **3**, 108-19; *P. A.*, **51**, 511-18, 563-7, 1943, will serve to complete the colorful record of the early history of the two well-known Tucson irons.

AN ARTICLE ENTITLED "THE TUCSON METEORITE," FROM THE *Arizona Citizen*, TUCSON, ARIZONA, JANUARY 15, 1876:

"In recent numbers of the *Washington Chronicle*, some interesting articles have appeared on the discovery, transportation, and presentation of a great meteoric stone [meteoritic iron], which has been designated the *Irwin-Ainsa Meteorite* but which will be known in the future as the *Tucson Meteorite*. It appears from articles in the *Chronicle* that Dr. B. J. D. Irwin, of the U. S. Army and now stationed at West Point, discovered this aerolite [siderite] in 1857 lying in one of the by-streets of our village, half buried in the earth, having been there a considerable length of time. As no one claimed it, Dr. Irwin, who had devoted

much of his time to the collecting of specimens of natural history for the Smithsonian Institution, determined to secure for the national collection at Washington this fine specimen of meteor[it]ic iron which he had found hidden away in the rubbish of an obscure alley in Tucson, which no person claimed, and which was looked upon simply as a curious and valueless object. In his correspondence with Professor Baird, the Doctor communicated his intention of forwarding it and presenting it to the Institution. Many army officers and others looked upon the idea as being impracticable, owing to the difficulty of transporting such a heavy mass over the bad roads of the country. Dr. Irwin persisted, however, and, under his guidance and with the assistance of several parties, the stone [iron] was finally landed in Washington. Mr. Palatine Robinson, near whose house it was, assisted in getting the stone [iron] as far as Hermosillo. Mr. M. Ainsa, who was in the business of freighting in the territory, conveyed it as far as Alamito, Sonora, whence, after vexatious delays of years, it was conveyed, free of expense, by Mr. Santiago Ainsa, to Guaymas, and thence, by the Holiday Steamship Company, to San Francisco, where, on its arrival, it attracted much attention. The meteorite arrived in Washington in November of 1868, was placed on exhibition, and became the great object of attraction in the Smithsonian Hall. There having been some dispute about the label put on this valuable stone [iron], by which it became known as the *Irwin-Ainsa Meteorite*, the matter was lately submitted to Professor Henry of the Smithsonian Institution, who has finally given his decision to having a new label placed upon the stone [iron], which reads: '*The Tucson Meteorite*, presented to the Smithsonian Institution by Dr. B. J. D. Irwin, U. S. Army, and transported from Tucson, Arizona, to Washington, free of cost, by S. Ainsa, the Holiday Steamers, the Pacific Mail Steamship Company, and the Panama Railroad Company.' This remarkable specimen of meteor[it]ic iron will constitute one of the main attractions in the Smithsonian display at the National Centennial Exhibition."

AN EDITORIAL ENTITLED "THE TUCSON METEORITE," FROM THE *Arizona Citizen*, TUCSON, ARIZONA, JANUARY 15, 1876:

"Now here is as pretty a kettle of fish as ever was seen! In the first place, we ask our reader to turn to our first page and read the article under the above heading; after reading that, we ask the reader to hear us. In some late numbers of the *Washington Chronicle*, we found interesting accounts of the great scientific curiosity called the *Tucson Meteorite* and the account we give on our first page is the same as [that in] the articles mentioned. We were very glad to hear of this wonderful aerolite [siderite] and, in reveries of imagination which we had, [we pictured] that, sometime in the lapse of ages past, this strange visitant had fallen like Lucifer from the scenes of its birth, childhood, first boots, and maturer life, and, choosing Tucson from among all the favored cities of the Earth, had taken this for its resting place! We felt that this conduct was proper and fitting, [as] we have not been the favorites of fortune to any extent. Other cities have monuments, glue factories, independent newspapers, and men who lived wholly for others, but we have none of these, and, tho we sometimes found an aching void, we have learned to kiss the rod! We believe, tho, if anyone could have pierced the smooth surface of this apparent submission, that away down in the hearts of our best citizens would have been found an unsatisfied, tho perhaps morbid, longing for a meteorite! Recognizing this feeling and condition of the popular mind, upon reading the account [that] we have compiled on our

first page, of the great Tucson aerolite [siderite], the aching void in our bosom was filled as it could never have been filled merely by the scientific importance of the discovery, and we hastened to share our pleasure with the public. But there is a thorn in our rose. According to the accounts of some of our oldest citizens, the history of the meteorite, as given by the *Washington Chronicle*, is erroneous in detail, and, while the main facts are correct, it seems proper to correct some minor details wrongly stated. From conversation with some of the people of Tucson who lived when the fragment of iron was found and when it was sent away, a period extending from 1857 to 1862 or 1863, the following facts appear. The aerolite [siderite] was discovered by Señor Ramon Pacheco on the northwest side of the lower range of the Santa Rita Mountains, southeast of town. Mr. Pacheco was a worthy blacksmith and had a shop in town. When he found the mass of meteor[it]ic iron, it weighed some 400 or 500 pounds, was about 4 feet long, a foot thick, and, having a smooth, flat surface on one end, it occurred to the finder to bring it to town and [that], by setting it upright in the ground, it would answer very well the purpose of an anvil in his blacksmith shop; this he did. It was in this blacksmith shop and in daily use when first discovered and taken notice of by the military authorities. It was clearly his property, and he was proud of it. This was natural, for where was there a smith, for miles around, who could boast of having an anvil probably discarded by Vulcan himself? Many a pleasant hour had its earthly owner whiled away, thinking of possible thunderbolts ordered for Jupiter, that had been fashioned on its clear-ringing face! To get possession of this valuable specimen, Mr. Pacheco says, the military officers promised to supply him with a new anvil from the quartermaster's department. Upon this promise and after urgent request, he let them have his Vulcanic anvil and he closed his statement by declaring that, since that time, he has never seen his aerial anvil or any consideration or return for either of them or any part thereof! Let us drop lightness of speech and get down to business. We are unprejudiced in the matter, unless it would be a strong prejudice in favor of anyone who undertakes the frequently thankless task of bringing to light a natural curiosity. But there is something in this that has an unpleasant ring. Mr. Pacheco is a good and truthful citizen, and it should be understood [that], at this time, and, therefore, at the time he made this statement about the circumstances of the meteor[it]ic anvil's being taken from him, he had heard nothing of the Washington version. We should regret the necessity of calling the attention of the Secretary of the Smithsonian Institution to the possible injustice done by his label on the meteorite and we deprecate a Congressional investigation, but is there any difference between the statement that a valuable curiosity is found and recognized in a pile of rubbish on a village backstreet and a statement that the same relic is obtained from a worthy and appreciative owner, by an unfilled promise of considerable reward?"

An Article from the *Arizona Citizen*, Tucson, Arizona, April 1, 1876:

"In the issue of the *Citizen* dated January 15, we quoted and commented upon an interesting account found in the *Washington Chronicle*, of the meteor[it]ic specimen discovered in Tucson in 1857 by Dr. B. J. D. Irwin, of the U. S. Army and now stationed at West Point, and which, after persistent and persevering energy, the Doctor finally succeeded in getting to the Smithsonian Institution in Washington. In making inquiries in town regarding this meteorite, we were positively informed by reliable parties of some unpleasant circumstances connect-

ed with the manner of obtaining a meteor[it]ic fragment at the identical time of the stated discovery and forwarding of Dr. Irwin's specimen. Never having heard of but one and naturally supposing that all accounts referred to one and the same specimen, in a separate article in the *Citizen* issue referred to, we published and commented upon the unpleasant features connected with a meteor[it]ic specimen found here and taken away between 1857 and 1863. These articles having come to the attention of the Secretary of the Smithsonian Institution, he has made inquiry and ascertained [that] there were, and perhaps are, two Tucson Richmonds in the field and that, [in] attaching our unfavorable comments to the meteorite found by Dr. Irwin, we were in reality referring to an entirely different specimen, one forwarded to San Francisco in 1862 or 1863, by General Carleton; and so, in attaching our unfavorable comments to the specimen found and forwarded by Dr. Irwin, we are doing that gentleman a deep injustice; we deeply regret this. Our disposition at the time [was], and always is, to be prejudiced in favor of those who endeavor to make man better, wiser, or happier. If Dr. Irwin has any revengeful feelings against us, they might be assuaged by knowing that the supreme gratification to us of learning that Tucson has produced two noted meteor[it]ic specimens instead of only one is nearly spoiled by learning that we have done him an injustice. Below we give Secretary Henry's letter:

"'Smithsonian Institution, Washington, D. C., February 23, 1876.

"'Editor, *Citizen:* This Institution has received your paper, in which you refer to the Arizona meteorite obtained by Dr. Irwin. In reply, we beg leave to say that there is apparently some misapprehension in regard to this subject and that your remarks apply to a second meteorite, also obtained in Tucson, sent some years ago by General Carleton as a present to the City of San Francisco. It was this specimen which had the anvil shape and which we understand was used for that purpose in Tucson. An additional reason for referring your article to the San Francisco meteorite is found in the statement you make as to the specimen's weighing 400 or 500 pounds and being 4 feet long and a foot thick, with a smooth, flat surface at one end and answering as an anvil. The Smithsonian one is shaped like a signet ring, is without any surface that could have served as an anvil, and its weight is between 1400 and 1500 pounds. Very truly yours, JOSEPH HENRY, Secretary.'"

A LETTER FROM THE *Arizona Citizen*, TUCSON, ARIZONA, APRIL 8, 1876:

"Editor, *Citizen:* I have read with pleasure, in your edition of January 15, a résumé of the history of the Tucson meteorite, but regret to perceive by your editorial comments thereon that you have been misled into confounding this specimen with another which was taken from your city later. When I first visited Tucson in 1857, there were two meteorites there. One, the great meteorite, was unclaimed and was half buried in the earth in one of the by-streets; in shape it was like a great signet ring, weighing some 1400 pounds, and had a diameter equal to that of a small carriage wheel. It remained in Tucson, waiting transportation from that time, until the autumn of 1861, more than three years, without anyone's questioning my claim and publicly announced intention to present it as my property to the Smithsonian Institution. The other was a smaller specimen, a block of irregular shape estimated at 400 pounds, less than one-third the weight of my specimen. The small one at that time was used as an anvil by a Mexican blacksmith, who doubtless is the claimant, Señor Pacheco, referred to in your

remarks. When Arizona was reoccupied by the United States forces from California in 1862, the late Major Carleton got possession of the smaller meteorite and soon afterwards sent it to San Francisco for presentation to one of the scientific institutions of that city, where it is known as the *Carleton Meteorite.* That took place two years after I had sent the great meteorite with which my name is connected. What arrangements may have been entered into by General Carleton or his agents to satisfy the claim of Señor Pacheco I know not, as I left the Territory in July, 1861, but it is only fair to assume that, owing to the onerous and pressing duties incident to an aggressive and active military campaign, ending in the subsequent transfer of General Carleton from Arizona to New Mexico, the propriety of recompensing Señor Pacheco was unintentionally forgotten. But few of the citizens who entered Arizona with the troops who took possession of the Gadsden Purchase in 1857 are now in Tucson to verify this statement, but, among the few who are still to be found in Tucson, are MM. William and Grant Oury and Mr. Estavan Ochoa, who can doubtless corroborate the above facts. From the foregoing it will be readily perceived that Señor Pacheco was in possession of his meteor[it]ic anvil two years after the specimen which I presented to the Smithsonian Institution had been removed from Tucson and that, if he has any unsatisfied claim for the one formerly used by him, he should state his grievance in a manner which will prevent people from confounding the meteorite obtained from him by General Carleton with that presented by me to the Smithsonian Institution. I trust that you will give this statement in your interesting journal and oblige. Yours respectfully, B. J. D. IRWIN, Col., U. S. Army, West Point, New York."

"Life on Mars" (Review)

Life on Mars is the title of a 50-page booklet (copyright, 1944) by Donald Lee Cyr of 1412 Palm Terrace, Pasadena 6, California. The following extracts are taken from pp. 49 and 50:

"The recent dominance of the meteoritic impact theory of crater origin makes timely a review of the oases-crater question of Mars. In this treatise, these conclusions have been pointed out:

"1. Meteorite craters are known on the Earth and Moon; therefore, craters exist on Mars.

"2. The circular oases on Mars are the size, shape, and number of comparable lunar craters.

"3. Crater depressions form a natural reservoir, accounting for the intense vegetation in the Martian oases.

"4. The random distribution of crater oases is apparent, indicating that the canal system was adapted to this haphazard arrangement.

"A new element of naturalness is added to the artificial appearance of the Martian network. Astronomy's disreputable urchin, Mars, can now take his rightful place in acceptable society."

"Why didn't someone think of the crater theory sooner? The answer is simple. Someone did. Back in 1892, at Arequipa, Peru, W. H. Pickering not only discovered the small black spots on Mars, but he also recognized their similarity to the circlets on the Moon. Because lunar craters were then believed to be volcanic, Pickering may be forgiven for implying that the Martian crater-

lets also were of volcanic origin.*"

Regardless of whether one is prepared to accept any of Mr. Cyr's rather novel conclusions, his brochure makes interesting reading and provokes thought.

F.C.L.

"*William H. Pickering, 'An Explanation of the Martian and Lunar Canals,' POPULAR ASTRONOMY, **12**, 439, 1904."

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VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By **LEON CAMPBELL, Recorder**

Radial Velocities of R and N Stars: R. F. Sanford of the Mount Wilson Observatory has recently published a study of the radial velocities of R and N stars to the number of 283 of which 136, about half, are known to be variable in light, and some of these particularly well known in the A.A.V.S.O. observing list. These are the very red stars which include such variables as R Leporis, X Cassiopeiae, V Hydrae, U and RS Cygni, and S Cephei. Twenty-eight of the variables of the N-type, in addition to the usual absorption lines, have emission lines of hydrogen. Six other N-type stars, not now known to be variable in light, may later prove to be variable.

There is strong evidence that these emission lines of H have variable radial velocities. The velocities derived from the emission lines are invariably smaller, algebraically, than those derived from the absorption lines, and the emission lines are at their maximum strength near maximum light, and practically invisible for a considerable interval before and after minimum light.

A plot of the class N stars shows a marked concentration to the galactic plane, with only 10 per cent of them located more than 30 degrees from that plane, and these prove to be predominantly bright stars whose actual distance from the plane can not be great. In contrast to these stars, those of magnitude 9.0 or fainter lie mainly within 10 degrees of the galactic plane. The galactic concentration of the class R stars is not so marked, although it is to be noted that these class R stars group themselves *above* the galactic plane between longitudes 140° and 300°, while between longitudes 300° and 140°, they extend well *below* the plane. This may be due partly to selection of the stars investigated.

When the velocities of the N-type stars are freed from solar motion and reduced to a mean apparent visual magnitude of 8.3, there is found to be evidence of differential galactic rotation. The mean distance found for the N-type stars, when so reduced, is 1.10 ± 0.008 kiloparsecs. The mean absolute visual magnitude becomes -2.3 ± 0.2, when the value of 0.35 visual magnitude is assumed for the general absorption per kiloparsec.

For 62 class R stars, 13 mean velocities were derived and these also show evidence of differential galactic rotation, but a lack of symmetry with respect to the axis of zero velocity. A mean distance for R-type stars is derived, for mean

apparent visual magnitude 9.0, of 0.67 ± 0.10 kiloparsecs, and an absolute visual magnitude of -0.4 ± 0.4 follows, when a general absorption of 0.35 magnitudes per kiloparsec is assumed.

The Eclipsing Binary U Cephei: The well-known eclipsing variable U Cephei has recently come in for a fair share of discussion, especially by Dr. Struve who treats of its spectroscopic problem. He finds that radial velocity observations made at the McDonald Observatory in 1943 tend to confirm the results obtained by E. F. Carpenter from similar observations made some twenty years ago, namely that the eccentricity of the spectroscopic orbit differs radically from that computed from the photometrically observed orbit, although Struve's value is much smaller than Carpenter's.

In the partial phases of the eclipse the lines of the brighter B8 star show a large rotation effect, which suggest that the equatorial velocity of rotation of the B8 star amounts to as much as 200 km/sec, this in spite of its greater size. This feature presents an interesting problem in cosmogony.

Struve also finds that the H and CaII lines during partial eclipse are displaced from those of the limbs of the B8 star, and give velocities of approximately +100 km/sec and −150 km/sec before and after eclipse, respectively. He also states that these lines are not produced by the G2 star, but would appear to originate in a thin stream of gas which may circle around the G2 star, a condition not unlike that of the streams found in β Lyrae and SX Cassiopeiae, as previously noted by the Yerkes astronomers.

Carpenter found a value for the eccentricity of 0.47, while Struve's value is only 0.20. On the other hand, the eccentricity computed from the photometric light curve should not be far from zero, since the secondary minimum, though of small depth, appears to come nearly half way between the two deep minima. Wendell obtained very few observations at secondary minimum, but Dugan made enough observations at that phase to establish the depth and time of this minimum. If the interpretation of the spectroscopic results were correct, the secondary minimum would occur 12.2 hours later than has actually been observed visually. Here lies a serious contradiction between spectroscopic and photometric results.

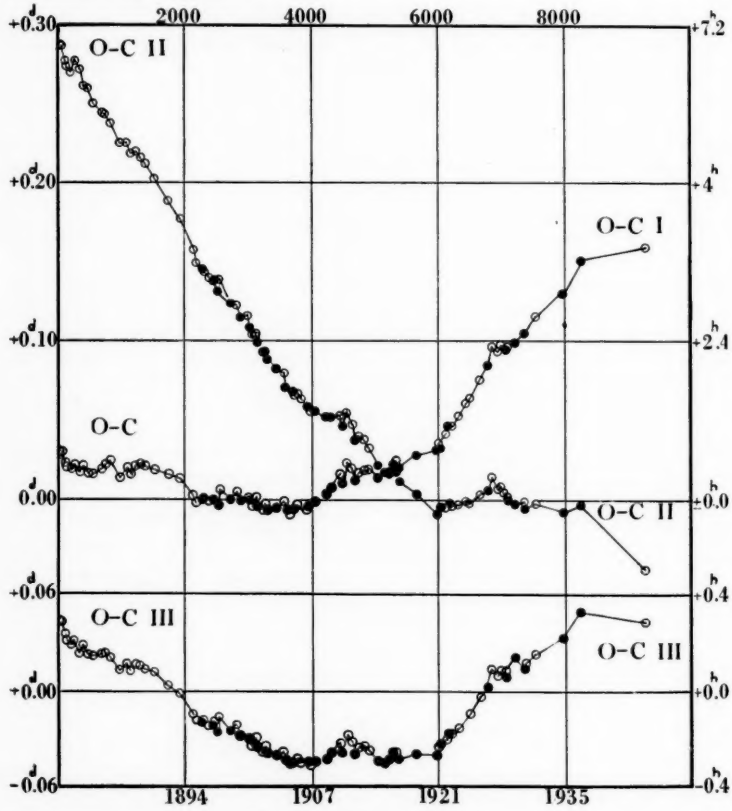
Both spectroscopic and photometric investigators agree regarding the general characteristics of the system of U Cephei. The brighter star is of type B8, or B9, and has a slightly elliptical shape, with its light contributing 0.84 of the total luminosity. The larger and fainter star is of type gG2, and contributes only 0.16 to the total luminosity, and can be observed only during the principal eclipse, which is total. There is a slight asymmetry in the visual light curve, as found by both Wendell and Dugan, more noticeable in the upper portions of the curve, and practically nil near minimum light.

Struve's velocity curve indicates a minimum at phase 0.56 days, and a maximum near 2.0 days. He concludes that while there is a possibility that the velocity curve is distorted by absorption in a gaseous stream, the evidence is not so compelling as in the case of SX Cassiopeiae.

Several studies of the period of U Cephei have been made in the past, particularly by Chandler in the early days, by Mrs. Shapley in 1916, and more recently, in 1933, by Carrasco. That the period is subject to changes, there seems to be little doubt. Probably the best material available for the study of changes in period is the photometric work begun by Wendell in 1895 and later continued

by R. S. Dugan, R. H. Baker, and Leon Campbell. Times of minimum from such observations can be derived within a few minutes, and therefore any O-C curves so derived can be considered as fairly accurate.

Recently Campbell has redetermined the times of minimum from the photometric observations made between the years 1895 and 1936. To do this task all the observations made between $0^d.1$ preceding minimum to $0^d.1$ following minimum were plotted by oppositions, and the curves so constructed superposed upon the first complete curve observed by Wendell in 1895-96, with the time of minimum accurately determined. The observations of Dugan and Baker were treated in a similar manner and referred to the 1895-96 curve for the derivation of the time of minimum. Also the partial runs obtained by Campbell, made solely for correction to period, together with a few runs made by graduate students at Harvard, were used, giving 33 points with which to construct O-C curves from photometric observations.



O-C Curves of U Cephei.
o = Visual; • = Photometric.

O-C values on the basis of Wendell's period, $2^d.492884$, and on the period $2^d.492934$, given in the 1940 Schneller catalogue, were derived and plotted on a convenient scale. Each O-C curve exhibits a marked deviation from regularity. The first-mentioned period satisfies the earlier Wendell observations, and the latter, those made after 1908.

Carrasco has listed the numerous visual determinations of minimum as made during the years 1880 and 1931. In order to determine how reliable such observations are, O-C values were computed on the two above-mentioned periods, grouping the minima per opposition. A plot of these O-C values, when compared with those derived from the photometric observations alone, shows a very close agreement, and gives us assurance that we may extend the O-C curves back from 1895 to 1880 with perfect confidence.

From all these results a mean average period of $2^d.492898$ seems to well represent the changes in period over a sixty-year interval. In the table are listed the mean heliocentric times of minimum for the various oppositions, with the number of the mean epoch, followed by columns of O-C I, O-C II, and O-C III, computed, respectively, on the basis of the following formulae:

$$\begin{aligned} \text{JD } 2407890.301 &+ 2^d.492884 \\ 2407890.041 &+ 2^d.492934 \\ 2407890.288 &+ 2^d.492898 \end{aligned}$$

The last column in the table contains the number of minima used in the mean for each opposition, or the letter indicating by whom the photometric observations were made: W, Wendell; D, Dugan; B, Baker; C, Campbell; and H, Harvard students.

Minimum JD 24	Mean Epoch	O-C I	O-C II	O-C III	No. Obs.
07900.301	4	+0.028	+0.288	+0.041	1
07940.189	20	+0.030	+0.289	+0.043	5
08027.440	55	+0.030	+0.288	+0.043	14
08154.570	106	+0.023	+0.278	+0.035	7
08214.396	130	+0.020	+0.274	+0.031	6
08398.868	204	+0.019	+0.268	+0.029	8
08553.430	266	+0.022	+0.269	+0.031	8
08737.899	340	+0.017	+0.260	+0.023	6
08887.476	400	+0.021	+0.261	+0.029	5
09081.916	478	+0.016	+0.253	+0.023	6
09253.925	547	+0.016	+0.249	+0.022	6
09615.396	692	+0.019	+0.245	+0.023	3
09757.493	749	+0.022	+0.244	+0.024	1
09964.400	832	+0.020	+0.238	+0.021	1
10310.905	971	+0.014	+0.225	+0.013	3
10605.072	1089	+0.020	+0.226	+0.018	7
10732.205	1140	+0.016	+0.219	+0.013	3
10921.669	1216	+0.021	+0.220	+0.017	1
11128.579	1299	+0.022	+0.217	+0.016	1
11342.966	1385	+0.021	+0.211	+0.014	3
11691.968	1525	+0.019	+0.203	+0.012	4
12225.442	1739	+0.016	+0.189	+0.004	2
12676.651	1920	+0.013	+0.177	−0.001	7
13180.204	2122	+0.003	+0.157	−0.014	4
13307.336	2173	−0.002	+0.149	−0.018	3
13576.569	2281	0.000	+0.146	−0.019	W
13616.457	2297	+0.001	+0.147	−0.018	5
13825.857	2381	−0.001	+0.140	−0.021	3
14002.853	2452	0.000	+0.138	−0.021	W
14025.291	2461	+0.002	+0.139	−0.019	1

Minimum JD 24	Mean Epoch	O-C I	O-C II	O-C III	No. Obs.
14154.915	2513	−0.003	+0.131	−0.026	W
14224.726	2541	+0.007	+0.140	−0.016	1
14668.453	2719	0.000	+0.125	−0.025	W
14920.239	2820	+0.005	+0.124	−0.021	6
15067.313	2879	−0.001	+0.115	−0.028	W
15381.418	3005	+0.001	+0.110	−0.028	5
15411.332	3017	0.000	+0.109	−0.029	W
15526.001	3063	−0.004	+0.103	−0.034	2
15698.016	3132	+0.002	+0.106	−0.029	3
15720.446	3141	−0.004	+0.099	−0.035	W
15902.424	3214	−0.006	+0.093	−0.038	2
16047.015	3272	−0.002	+0.094	−0.035	5
16116.812	3300	−0.006	+0.089	−0.039	W
16470.803	3442	−0.005	+0.083	−0.040	W
16782.417	3567	−0.001	+0.080	−0.038	1
16867.171	3601	−0.005	+0.075	−0.043	W
16959.404	3638	−0.009	+0.069	−0.047	7
17113.966	3700	−0.006	+0.069	−0.045	W
17153.852	3716	−0.006	+0.068	−0.045	7
17300.935	3775	−0.003	+0.068	−0.043	4
17440.535	3831	−0.005	+0.064	−0.045	7
17647.443	3914	−0.006	+0.058	−0.048	3
17692.317	3932	−0.004	+0.060	−0.046	W
17806.989	3978	−0.005	+0.057	−0.047	4
17996.452	4054	−0.001	+0.057	−0.044	W
18397.811	4215	+0.004	+0.053	−0.042	W
18619.682	4304	+0.008	+0.053	−0.039	W
18973.679	4446	+0.016	+0.053	−0.033	2
19033.503	4470	+0.011	+0.047	−0.039	W
19237.932	4552	+0.023	+0.055	−0.028	6
19427.388	4628	+0.020	+0.048	−0.032	4
19542.053	4674	+0.012	+0.038	−0.040	W
19566.982	4684	+0.012	+0.038	−0.040	2
19711.574	4742	+0.017	+0.040	−0.036	1
19933.443	4831	+0.019	+0.038	−0.035	1
20115.423	4904	+0.019	+0.034	−0.037	1
20454.450	5040	+0.014	+0.022	−0.044	D
20753.597	5160	+0.015	+0.017	−0.045	B
20903.173	5220	+0.018	+0.017	−0.043	C
20903.173	5220	+0.018	+0.017	−0.043	B
21077.679	5290	+0.022	+0.017	−0.039	C
21157.453	5322	+0.023	+0.017	−0.038	1
21292.065	5376	+0.020	+0.011	−0.043	D
22000.052	5660	+0.028	+0.005	−0.039	C
22827.693	5992	+0.031	−0.009	−0.040	C
22847.641	6000	+0.036	−0.004	−0.035	1
23054.552	6083	+0.038	−0.003	−0.033	C
23154.272	6123	+0.042	−0.004	−0.031	1
23251.499	6162	+0.047	−0.001	−0.026	C
23361.186	6206	+0.047	−0.003	−0.027	1
23637.902	6317	+0.053	−0.003	−0.023	1
23952.014	6443	+0.061	−0.001	−0.016	1
24106.575	6505	+0.064	−0.002	−0.014	2
24517.915	6670	+0.078	+0.004	−0.003	1
24804.604	6785	+0.085	+0.006	+0.003	C
24864.440	6809	+0.092	+0.012	+0.010	C
24951.696	6844	+0.097	+0.015	+0.014	1
25183.531	6937	+0.094	+0.007	+0.010	1
25325.630	6994	+0.098	+0.009	+0.013	1
25425.344	7034	+0.097	+0.005	+0.011	1
25557.465	7087	+0.095	+0.001	+0.009	C

Minimum JD 24	Mean Epoch	O-C I	O-C II	O-C III	No. Obs.
25557.467	7087	+0.097	+0.003	+0.011	1
25901.487	7225	+0.099	−0.002	+0.021	C
02670.439	7373	+0.104	−0.004	+0.014	C
06270.443	7373	+0.108	0.000	+0.018	1
26684.269	7539	+0.116	−0.001	+0.023	1
27748.744	7966	+0.130	−0.008	+0.031	H
28486.660	8262	+0.151	−0.002	+0.049	H
31036.889	9285	+0.160	−0.044	+0.043	1

The O-C curves are shown in the figure; purely visual determinations by circles, and the photometric values by dots. The last point on each curve represents a single value determined for a visually observed minimum by Struve in November, 1943.

The curve plotted on the basis of the O-C III—period $2^d.492898$—would appear to best represent the changes which have taken place in the period of U Cephei since its discovery without using additional terms in the formula. It is well known that when such a value of a period is assumed which produces considerable steepness of curve, compared to one with a smaller gradient, small changes are not too apparent. What U Cephei does in the future is purely a matter of conjecture. Further observations for the correction to the period should be made at least once or twice a year.

Observers for March: The list of contributors for the month of March follows, together with the number of variables observed and the number of estimates made by each.

Observer	No. Var.	No. Ests.	Observer	No. Var.	No. Ests.
Bappu	30	97	Luft	10	23
Blunck	11	11	Manlin	35	35
Bouton	26	28	Mary	12	15
Buckstaff	7	7	Nadeau	81	100
Dafter	14	30	Oheim	16	32
Fernald	232	431	Oravec	3	8
Ford	20	22	Parks	20	22
Garneau	24	24	Peltier	94	143
Halbach	18	18	Robinson	34	65
Harris	13	14	Rosebrugh	25	205
Hartmann	122	133	Schoenke	24	41
Holt	86	105	Sill	81	81
Howarth	16	16	Webb	13	14
Kearons	60	67	Weber	72	72
Kelly	10	13	Wolfram	3	3
de Kock	63	242	—		—
Koons	28	28	32	(Totals)	2145

April 21, 1944.

General Notes

We deeply regret the continuing lateness in the appearing of the several issues of this magazine. We had hoped that before this time the regular schedule, namely mailing on the first of the month, would be restored. However, the printer, although he is aware of the situation and is extremely eager to correct it, still finds himself under the necessity of carrying on with a staff of workmen

badly depleted by the demands of the war. We, therefore, bespeak patience on the part of subscribers and readers until the emergency is past. EDITOR.

Dr. Seth B. Nicholson, Astronomer in the Mount Wilson Observatory, will conduct the course in elementary astronomy in the Summer Session of the University of California, Los Angeles, from June 26 to August 4, 1944.

Dr. Harlan T. Stetson, director of the Cosmic Terrestrial Research Laboratory at Needham, Mass., addressed the Geological Section of the New York Academy of Sciences on April 3 on "Modern Evidences for Differential Movement of Certain Points on the Earth's Surface." (*Science*, April 21, 1944.)

Jesse Pawling, from 1925 to 1935 associate astronomer at the U.S. Naval Observatory in Washington, D. C., died on April 11 at the age of seventy-eight years. Mr. Pawling graduated from Cornell University in 1893 and, after several years of graduate work in other universities and teaching physics in Philadelphia, he went to the Naval Observatory in 1905, where for thirty years he worked on positional astronomy. (*Science*, April 21, 1944.)

Dr. Frederick C. Leonard, who has been in residence at the Lick Observatory since July, 1943, delivered a lecture, illustrated with specimens and slides, on "Immigrants from Space" (meteorites) before the Astronomical Society of Nevada at the University of Nevada in Reno on the evening of May 4, 1944. Professor G. Bruce Blair, of the Department of Physics and Astronomy of the University, is the President of the Society this year.

American Astronomical Society

The Seventy-second Meeting of the American Astronomical Society will be held in Philadelphia, Pennsylvania, on June 28-29, 1944, at the invitation of the American Philosophical Society. The sessions for papers and the business session will be held at the Hall of the American Philosophical Society. A tour of local points of interest, a special demonstration at the Fels Planetarium, and visits to the Flower, Cook, Sproul, and Haverford Observatories are to be special features of the meeting. The headquarters for members will be the Benjamin Franklin Hotel.

The Scottish Branch of the British Astronomical Association this year is completing the first half-century of its existence. This fact was recognized in a Jubilee Commemoration in Glasgow on April 20. The principal event of this occasion was a public lecture on the subject "Life on Other Worlds" by Sir Harold Spencer Jones, the Astronomer Royal.

The Milwaukee Astronomical Society of Milwaukee, Wisconsin, is continuing its activities even during these years when many peace-time programs have had to be abandoned. Recent evidence of the continued interest in astronomy on the part of this Society is a body of mimeographed material kindly sent us by the secretary, Mr. Herbert W. Cornell. A part of this consists of three large-sized mimeographed sheets entitled "Observations of Moon and Planets in 1944." This affords detailed information for those who wish to make naked-eye observations or to use field glasses or small telescopes.

Another part, a somewhat more general document, consists of six closely mimeographed pages and covers not only the moon and the planets, but stars and other objects of interest in the sky. It also contains a chart showing the position of the Great Dipper at various seasons during the year. It also gives the elementary astronomical facts which a beginner needs in the early stages of his astronomical adventure.

The Society is to be congratulated upon the valuable service it is rendering in this way.

Occultation of Jupiter by the Moon

Date—April 30, 1944.
Observer—Walter H. Haas.
Telescope—Flower Observatory 18-inch refractor, Upper Darby, Pa.
Used 150 × (photometer eyepiece).
The seeing was 1½ on a scale of 1 to 5, with 5 best.
The transparency was 4 on a scale of 1 to 5, with 5 best.
Times given are P.M., E.S.T.

First contact was observed to occur at 2:47:40. The dark limb of the moon was seen projected upon Jupiter at 2:47:42; but contact was then necessarily past, and I estimate that it came two seconds earlier. Second contact occurred at 2:49:11. It was observed well, and this value should be accurate to within two seconds. Third contact was at *about* 4:02:00. This value is worth little; I watched the wrong portion of the limb for the planet, and it was well past contact when it was first seen near 4:02:10. Fourth contact was timed at 4:04:32. Though this contact was apparently harder to observe than second contact, the value just given should be accurate to within a few seconds.

As Jupiter emerged from behind the dark limb of the moon, the dark band across the face of the planet and concentric with the lunar limb frequently reported to be present under these conditions was seen. It was not seen when the planet was at the dark limb of the moon. The satellites were invisible.

May 1, 1944. WALTER H. HAAS.

The Nature of Cosmic Rays

If our eyes could be made to magnify what they now see 10 million million times, the space which is around us would look something like a turbulent thunderstorm with the rain and hail pouring down from all directions. In this deluge around us would be found, in varying degree, free from the encumbrance of matter in bulk, about all the atomic particles which the physics of the last five decades has forced out of that seclusion where nature has held them secret from the prying eyes of those as close to us in time as our grandfathers. An atomic umbrella would be worse than useless in shielding you from this atomic thunderstorm; for even an armor of lead would only enhance your troubles by irritating the particles of this cosmic rain to the point of propagating their species in the armor and deluging you more than if you had not sought to protect yourself. Traveling with speeds a million times greater than that of a bullet from the highest power rifle known, these particles are now shooting right through your bodies at the rate of about 10 per second for each one of you. Each of them is tearing apart about a million of your personal molecules as it passes through you, so that you each have some 10 million molecules damaged per second. Do not be alarmed, however, you are not wearing away very fast. A speck of dust which

is almost invisible contains a million times as many molecules as there are people on the face of the earth. You can afford to lose a few million. These mysterious raindrops, this artillery fire, which space spreads as a continual barrage around you, constitutes in its totality what we call the *cosmic radiation.*

Introduction to paper by W. F. G. Swann in *Sky and Telescope*, May, 1944.

Sigma Xi Expansion

The Society of the Sigma Xi, national scientific honor society founded at Cornell University in 1886, with local members organized as chapters or clubs in about 125 American universities and colleges, is extending the fulfillment of its organic purpose of the "Encouragement of Original Investigation in Science, Pure and Applied" by encouraging member group activity in non-academic research institutions which qualify because of their participation in and encouragement of original research in science.

The first industrial research group to qualify and be granted affiliation with Sigma Xi is the Esso Research Club, of Elizabeth, New Jersey, whose membership is drawn from the chemists, physicists, engineers and other technical research and development personnel of the companies associated with Standard Oil Company (New Jersey).

The Executive Committee of Sigma Xi, at a meeting on December 3, 1943, voted unanimously to approve affiliation of the Esso Research Club.

The installation of a chapter of Sigma Xi in the name of the Esso Research Club, Bayway and Elizabeth, New Jersey, was made on April 26. Dr. Harlow Shapley, director, Harvard College Observatory, and president, The Society of the Sigma Xi, presided at the installation meeting.

Book Review

Marine and Air Navigation, by John Q. Stewart and Newton L. Pierce, Princeton University. (Ginn and Company, Publishers. 473 pp. $4.50.)

One of the most immediate academic consequences of the war was a sudden and enormous increase in the demand for teaching in navigation. Most astronomers had been accustomed to devote a lecture—or half of one—in their general courses on astronomy to the principles of celestial navigation, and a few hours of student work in practical astronomy to the sextant; but almost always as an incidental part of the course. The approach was usually "astronomical" in an old-fashioned sense—the observations were made with an artificial horizon, and reduced to find the latitude or the time by methods probably familiar to Bessel. When the hard-worked professor of mathematics in some small college found teaching in astronomy added to his obligations, he sometimes treated navigation primarily as a branch of spherical trigonometry.

Neither of them was to be blamed. The problems of celestial navigation provide admirable exercises in trigonometry; and if a student in practical astronomy has learned to use a sextant quickly and accurately, he has mastered as severe an instrumental discipline as it is fair to impose upon an undergraduate.

But the students who thronged the new wartime classes needed something radically different. They might, and their superior officers surely would, have to practice navigation, at sea or in the air, when their lives, and perhaps the

success of the operations in which they were engaged, depended upon the correctness of their calculations, and the speed with which they were made. Navigation was now taught for its own sake; but the new courses, though "vocational," had no less "cultural" value than the old, since the introduction of other branches of navigation than the celestial greatly enriches their content.

The new teaching of navigation at Princeton began two weeks after Pearl Harbor, and has been actively conducted ever since. The two men who did much the most of it have put the results of their experience into a very good book.

The approach is comprehensive, "with marine and air navigation evenly handled at every point, with mathematics entering always as the servant and never as the master of the navigator." To make sure that mathematics will be an efficient servant, each major topic—spherical coordinates, plane trigonometry, and the spherical geometry of celestial navigation—is introduced by an elementary treatment at the high school level—a policy whose soundness will be endorsed by any one who is familiar with the present situation. The treatment is operational; the student is fully informed of the nature of the problem which must be solved, and trained in the most efficient methods of solution, while the purely mathematical aspects are subordinated. *E.g.*, "It is unnecessary for the practical navigator to understand Ageton's table in order to use it. He need only follow a set routine . . ."—after which the trigonometry of the method is clearly explained in small type for the more advanced student. Not a single example of formal logarithmic calculations appears in the book. It is pointed out that such are necessary in long-range Mercator or great-circle sailing—and also that the resulting accuracy in the calculated course and distance go far beyond that with which the actual course can be steered or distance logged.

For similar reasons, the *American Air Almanac* is the one primarily described in the section devoted to the subject, the *Nautical Almanac* being discussed briefly —and the *American Ephemeris* mentioned only for its longer list of star places. The very good reason is that the limitation of the first to 1′ permits very rapid and fool-proof methods of interpolation; the second, going to 0′.1 demands more laborious interpolations, by different methods for different objects, while the additional accuracy can very seldom, if ever, be approached by sextant observations at sea, and certainly never in the air; while to work to 0″.1, with the third, would be sheer waste. An excellent section on tolerances indicates clearly just how far the navigator may safely use approximation, and when he should not. The vital importance of accuracy within these limits, of orderly work and clean labeling of diagrams, and of checking and re-checking everything—by additional observations, whenever possible—is stressed again and again.

The book aims to be a comprehensive textbook for the student—not a compendium for the expert. No attempt is therefore made to provide the full tables which are necessary for solving the astronomical—or navigational—triangle. Excerpts are given from the standard tables (*H.O.* 211 and 214), and also from the *Traverse Tables*, the *Air Almanac*, and the *Nautical Alamanc*, sufficient to enable the student to work out the drill problems.

In such a treatment, the relative space given to different topics reflects the judgment of the authors. For example, certain refinements of navigation which are useful under special circumstances—such as getting a fix when the ship's latitude nearly equals the sun's declination, by observing the sun near the zenith a little before and after noon, and drawing the Sumner *circles* on the chart—are

barely mentioned; and the advice that sextant sights of bodies near the zenith should be avoided (p. 311) appears to be too sweeping. The more important case of identifying a star observed through a gap in clouds is discussed in some detail.

The nine pages devoted to the compass give a full and clear explanation of the nature of variation and deviation, and a short account of the devices by which the latter is compensated—referring to Dutton for the details. Practically important matters are stressed,—such as the necessity of redetermining the deviation whenever important changes are made in the ship or cargo, and of learning to correct for known compass errors with speed and certainty—and the dangerous northerly turning error in the air is fully discussed.

The 27 pages on map projections contain more than the beginner needs—but the discussion is accurate and illuminating. The authors regard the Lambert projection as "definitely inferior for precise navigation" to the Mercator—but make it clear that differences of opinion exist.

The system of aids to navigation—lights, buoys, etc.—used in channel piloting is well described and illustrated, and the use of Coast Pilots (sailing directions) and lists of lights is excellently explained by reproducing pages dealing with the region shown on a chart which is also reproduced. The chapter on "contact" flying contains very good advice about map reading, choice of landmarks to be looked for, and the vital importance of never losing touch with one's map position. The discussion of Coast Piloting introduces the student to lines of position, and to ordinary and running fixes, with many good diagrams, in which all lines are marked according to standard naval practice.

The chapter on tides and currents refers to other works for the theory, but gives full details for the use of the *Tide and Current Tables.*

One of the most distinctive and valuable parts of the book is the thorough discussion of relative motion, at sea and in the air, which occupies sixty pages. The vector diagram is introduced in a discussion of correction for current or wind,—including drift-sight methods for determining wind in the air,—and applied successively to problems of maneuvering at sea, and of scouting, interception, and return to the carrier in the air. These problems, which are of remarkable variety, are solved graphically on the *Hydrographic Office Maneuvering Board Sheets.* More than twenty such plots are reproduced, and clearly explained in detail. The student who masters these will be well prepared for intensive study in later military or naval training, and the civilian, in time of peace, will find them of great inherent interest.

The treatment of the sailings is again rather full. Radio navigation is justly given a chapter to itself. The nature of the disturbances which limit the accuracy of present radio bearings is clearly explained. Radar is mentioned—all that can be done till after the war.

Celestial navigation is brought down to earth as soon as possible—the fundamental triangle being on the spherical "navigator's earth" with vertices at the terrestial pole, the observer, and the geographical position (GP) of the body observed. The declination of the body is defined as the latitude, and its Greenwich hour angle as the longitude of the GP. This startling method has proved very useful in teaching navigation to students who have never previously been exposed to astronomy. The descriptions of the sextant and bubble octant are concise but adequate, that of the corrections to observed altitudes is thorough.

In working meridian sights, diagrams are recommended rather than memor-

ized formulae. All other sights are reduced as Sumner lines by St. Hilaire's method. For finding the computed altitude, preference is given to the *Tables of Computed Altitude and Azimuth* (*H.O.* 214) whose use is fully illustrated by examples. The use of Ageton's camouflaged logarithmic tables (*H.O.* 211) is also fully illustrated, while other methods—*Dreisonstok's tables, Weem's Line of Position Book,* his *Star Altitude Curves,* and the old cosine-haversine formula are explained.

At the end of the book come chapters on Astronomy for Navigators (fourteen pages of the "doctrine of the sphere" and seven on "astronomy of general interest"), on U.S. Government Agencies which Aid Navigators, and on the history of Navigation, and finally 275 drill problems, covering all phases of the subject.

An excellent series of star charts ends the volume.

It is very well illustrated. The numerous diagrams are clear and accurate—except for a very few taken from a widely-circulated magazine which may confuse some students, despite the warnings in the captions. The colored plates are excellent, and the reproduction of charts satisfactory, except for a couple of small scale coastwise charts which have been so much reduced that the soundings are illegible. The photographs are well reproduced. Most of them have an obviously functional relation to the text, but there are a dozen or so—mostly very fine pictures—for which the relation is less obvious to the reviewer—who may be of the old school. The elimination of a couple would have provided space for expansion of the ingenious "long-term almanac" (from which the GHA and Dec of the sun and a selection of the Navigators' Stars can be found with an error not exceeding 2′ for any time up to 1955) so that the corrections for second differences could have been avoided.

This is an outstanding book, which presents a clear, accurate, comprehensive, and thorough treatment of the problems and methods of navigation at the present time. It is heartily to be recommended to both teachers and students.

HENRY NORRIS RUSSELL.

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge receipt of the following named publications and express their great appreciation of the courtesy shown on the part of those who have sent them.

Annals of the New York Academy of Sciences:

Vol. XLIV, Art. 1. "Boundary-Layer Problems in the Atmosphere and Ocean," by C. G. Rossby, B. Haurwitz, Benjamin Holzman, Woodrow C. Jacobs, A. A. Kalinske, Phillip Light, R. B. Montgomery, and H. U. Sverdrup.

Art. 3. "Parasitic Diseases and American Participation in the War" by Horace W. Stunkard, Lowell T. Coggeshall, Thomas T. Mackie, Robert Matheson, and Norman R. Stoll.

Art. 6. "Psychosomatic Disturbances in Relation to Personnel Selection" by Lawrence K. Frank, M. R. Harrower-Erickson, Lawrence S. Kubie, Gardner Murphy, Donal Sheehan, and Harold G. Wolff.

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